THE

# AMERICAN JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.



FOURTH SERIES

VOL. XLVIII—[WHOLE NUMBER, CXCVIII].

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# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

## Art. I.—*Present Tendencies in Paleontology;** by Edward W. Berry.

When a few days ago your president asked me to take part in the meeting to-night I felt bound to accede for friendship's sake, rather than because of any message I had to deliver. On the eve of my departure from the country I have had no time to formulate and marshal what few ideas I have on the subject. Your president in his wisdom must have had a motive, otherwise why call in an Antony when Washington is full of Brutuses. Recognizing as I do certain iconoclastic temperamental trends in myself, I suspect that he may expect that I will lay about me lustily in an endeavor to crack a few heads, and in the words of the poet "stir up the animals." I am resolved, however, to overflow with the milk of human kindness, and to shed sweetness if not light upon the subject.

One is embarrassed to decide whether to attempt the difficult role of historian of present tendencies where there is such grave danger of not seeing the forest because of the trees; to take the allotted time in criticism of past and present accomplishments in paleontology, or in an endeavor to sketch the things hoped for in the golden era of the future.

The normal course of events has been so muddled by world conditions during the past few years that it is difficult, nay impossible, to discern with any clarity the present trend in paleontologic research. If I were asked to state the tendencies as they appeared to me prior to 1914, I could do no better than sketch certain trends that

* Address read before the April meeting of the Geological Society of Washington.

were essentially nationalistic, although such generalizations inevitably do great injustice to individual genius in all countries, and like all generalizations are only entertaining half-truths.

Paleontologic work in France, particularly in the vertebrate and plant fields, was characterized by breadth of view and philosophy of interpretation such as it has always exhibited and men like Douvillé and Kilian in the invertebrate field were fully sustaining the national tradition. Perhaps nowhere have the problems of faunal facies and their lateral variations been as conclusively solved as in that country. German paleontology ran true to the racial temperament. The quantity of detailed descriptive work was probably greater than in any other country, the quality was not especially high and there was no correlation between facts and fancies. The scramble for self-advertisement and professorial advancement may be illustrated by Steinmann's wild book on evolutions, or Jaekel's speculations on the classification of trilobites, or Arldt's book on paleogeography, or to go back to an earlier day by the factory for the manufacture of subjective phylogenies which Haeckel operated at Jena for so many years. Crossing the channel you will, I think, agree that British paleontology had the solid qualities characteristic of things British. Oftener than not the work was absolutely solid. The point of view was still that of the founders. Whatever had been good enough for Sedgwick or Murchison should be conserved to the bitter end. The younger generation was busily engaged in trying to make over and patch the outworn garments of paleontology, not daring to suppose that what had been insoluble to the grand old men of British geology was capable of solution. (I quote substantially from a letter from an English friend.)

One cannot probably get into a sufficiently detached frame of mind to visualize correctly the true position of the United States in the present status of paleontology. I think we undoubtedly exhibit a provincialism and radicalism that goes with young nations as with young individuals. Of one thing I feel reasonably sure, namely that the future belongs to us if we keep our ideals high enough. Our scientific, like our economic, opportunities, are very great.

A French paleontologist borrowing the metaphor from

the diurnal rotation of the earth writes me that the paleontologic sun is setting in Europe while the dawn is just breaking in America. After making the proper deduction for the felicity of Gallic politeness there is a grain of truth in the figure.

The two Americas stretching from the abundant Arctic lands to the north of our present continent, southward far into the southern zone, and with a very obvious former connection with Antarctica; possessing a fairly typical representation of all the great systems of rocks except for the weakness of our known Permian, Triassic and Jurassic history,—no region on the earth is as strategically located for the solution of problems of earth history or the former distribution of life—both marine and terrestrial.

We are, then, "called to a high calling" and have a mission to fulfill beside which the imperialistic dreams of reactionary political prophets are but as ships that pass in the night.

In paleontology, as in all branches of human endeavor, there is nothing more obstructive of progress than a reverence for old ideas and systems which have outlived their usefulness. This is especially to be guarded against in an organization where rules and standards have to be formulated for the guidance of field parties and where there is an obvious necessity for laying down certain classifications for the presentation of results in reports and upon maps. There is a tendency, well illustrated by the Geological Survey of the United Kingdom, for official sanction to lag about a generation behind the advance of knowledge. On the other hand there is the great danger that we in America, in a scientific isolation paralleling our former political isolation, filled with pride at the size of our country and the number of pages of geological contributions printed annually, may neglect not only the past but the present state of our science in other lands. I believe that a knowledge of the historic development of paleontology and the details of the European succession is of the utmost importance, for Europe is after all historically the type continent despite the untypical development in a world sense of so many of its geological horizons.

Undoubtedly the geological history of North America is much fuller and more normal than that of Europe, as

has been frequently pointed out, and if civilization had flowered first in the Western instead of the Eastern hemisphere, we should have to-day a much more logical geological column. But it was otherwise ordained, and if, adopting the insular motto that North America is good enough for us, we make our scientific horizon coincide with our political horizon, we lose that breadth of view and perspective that is such a necessary part of our philosophy. We exchange for the vocational state of mind of a State University that intangible leaven indicated by the much abused word culture, which depends on point of view or perspective. The average European paleontologist has almost invariably a more cosmopolitan viewpoint than the average American paleontologist—an outcome of his training and the fact that the world is his field. It seems to me that proposals such as the elimination of the Permian as a system, or the lumping of the Triassic and Jurassic into a single system, are examples of our provincial point of view, entirely ignoring, as they do, the great development of marine series of these ages in other parts of the world.

The inertia of old ideas and the vitality of traditions, even in radical minds, is astonishing. Witness the slow death of the notion, inherited from Brongniart, that the formation of secondary wood in stems, such as Sigillaria, stamped their possessors as exogenous seed-plants. Witness the implications, still alive and vigorous, that march in the train of the notion that an Age of Reptiles is a chronologic and geologic unit. Perhaps the most striking instance of what I am seeking to illustrate is furnished by the survival of Cuvier's conceptions in stratigraphic paleontology. I doubt if there lives a paleontologist who would defend the theorem that faunas or floras were repeatedly exterminated by cataclysmic revolutions and renewed by special creations, and yet when you see the average paleontologist in action, his logic is inevitably colored by the assumption that a floral or faunal unit had an objective reality and is not merely a cross section of the tree of life at a particular time. Nothing it seems to me is more pernicious than the idea that, perhaps poorly determined, formational boundaries are circuit breakers in the continuous life stream that has flowed down to us from the immeasurable past. This is especially illustrated in the discussions of the

more important boundaries. Where a well-marked time-interval intervenes between two normal marine units exposed to our investigation, it is easy sailing, but when the hiatus is small or is partially bridged by marine formations elsewhere, or by preserved continental sediments—disputation is endless. I need only cite in support of this contention the Hercynian, Rhaetic, Wealden and Laramie questions. When terrestrial sediments and life replace marine sediments and life in a single section or vice versa we insist that the particular marine fauna vanished or appeared with the particular retreat or advance of the sea in that region and that the terrestrial fauna and flora appeared or vanished with the deposits in which it is found. That the terrestrial and marine organisms were contemporaneous over a much longer interval than is represented by the particular associated deposits is apparently never considered. This might be illustrated by a discussion of the age of some of our Cretaceous formations, but I pass on to the broader question, often lost to view, that our systematic units in so far as their contained floras and faunas are concerned are purely subjective academic pigeon-holes and if we had the whole record we probably could not differentiate Silurian from Devonian, Jurassic from Cretaceous or Oligocene from Miocene. We have hoped for much from the so-called method of diastrophism, and it has undoubtedly immeasurably widened our stratigraphic horizon and rationalized many outstanding problems. As an absolute criterion for the determination of larger units or as affording the basis for the rhythmic time-table, it was foreordained to failure. I can see no more reason for assuming that two successive cycles of sedimentation correspond in relative duration, than there would be for assuming that because a man, a turtle and an elephant are born, live and die, that all endure for the same number of years. Any succession of changes is in a sense rhythmic, but the elaboration depends on the location of a particular section with respect to the direction and distance of the basin from which the trangression emanated. We would make a sorry mess of it did the segregation of Permian, Triassic or Jurassic rocks depend on their visible development in North America. The mid-Tertiary section in the northern Paris basin represents nearly continuous sedimentation while farther

south there are many breaks. Neither section could be correctly interpreted in the absence of the other.

Progress in paleontology can only result from the action and reaction of the two parallel lines of human endeavor, namely, the accumulation of facts through exploration, research and discovery, and the elucidation of the accumulated facts through advances in philosophic interpretation. The temple of science remains merely a pile of bricks and stone until each brick and stone is fitted into its proper niche. These two lines of endeavor rarely develop proportionately. The accumulation of fact usually far outruns their adequate interpretation, for example, paleontology made rapid progress in the early years of the 19th century through the discoveries of Cuvier 1769-1832 and because of his genius as a comparative anatomist. It was checked by his conspicuous failure as a natural philosopher, exemplified in the invertebrate field by d'Orbigny's (1802-57) 27 distinct creations. His successor Owen (1804-1892) was similarly endowed with gifts of descriptive industry and was a still greater failure as a philosopher. The slowing of the wheels of progress by false philosophy is well illustrated by the historic influence of the dogmatic doctrines of the so-called Neptunists emanating from Werner and his students (1750-1817). One might mention many similar instances nearer our own day if more were necessary.

It would be a fine thing if paleontologists could imitate the practice of business concerns in periodically taking an inventory and making up a balance sheet, writing off the moribund theories and discarding obsolete methods, and determining if there was sufficient gold in the treasury as a reserve for the paper in circulation. For years, invertebrate, vertebrate and plant paleontologists have seemingly been largely actuated by a desire to merely multiply the diversity of the organic record. Zittel was the first to bring into prominence the truism that fossils are not primarily "things dug" and to be studied like minerals, but as belonging to the dynamic world of once living things—a part of a biota and something multifariously interacting with the particular organic and physical environment. Vertebrate paleontology has probably been foremost in stressing the biologic aspect of the subject, while the others and particularly the plant

side have lagged behind. Stratigraphic paleontology cannot, however, be divorced from biological paleontology without becoming sterile. Historical geology which is the ideal we strive for is a vast synthesis woven of many diverse strands—the warp is stratigraphy but the vari-colored woof is furnished by a multitude of criteria and we cannot ignore a single leaf lobe or venation pattern or tooth cusp or bone facet or loop pattern or hinge plate without a knot or break in the fabric.

Fossils are not to be looked upon merely as medals of creation to be transmitted to the paleontologist for report, resulting usually in a hasty and ill considered list of "sp"-'s, "cf"-'s and question marks, to be used as padding for some printed report. Neither is there room in our science for the closet naturalist who cannot see a contract nor tell the bottom from the top of a section in the field. Paleontology is equally crippled whether divorced from biology or stratigraphy.

Bird's-eye methods that cannot discriminate between mid-Cretaceous and mid-Tertiary Foraminifera are of no service to geology. Loosely drawn genera and species are no longer useful. Witness the transformation of the genus Olenellus into the wonderful family Mesonacidæ in the skillful hands of a Walcott. The precise systematic methods introduced by Waagen (1869) and so largely exemplified in the work of Ulrich and David White, which seek the recognition of the most minute mutations—often somewhat contemptuously referred to as the splitting of hairs—is the only method by which paleontology can contribute to stratigraphy. In paleobotany the older bird's-eye obscurantist method has no living champions and the time is not far distant when all loose generic aggregates like Spirifer and Venus or Zamites will join the limbo where now dwell Ammonites, Goniatites and Ceratites, and only emerge as useful descriptive terms purged of generic significance. The same is true of broadly conceived specific aggregates. The poorer the diagnosis and illustration of a species at the hands of the paleontologist, the greater the variety of diverse things that come to be called by the same name, and I could give you many illustrations proving that the more common names in lists drawn up from different regions, particularly if they are the work of the earlier workers, are absolutely worthless. This is espe-

cially true of the work of Ettingshausen, Geinitz, Lesquereux, and their contemporaries in Carboniferous paleobotany. Even where identity seems assured as in dealing with cortical remains of forms like Sigillaria and Lepidodendron, assumed cosmopolitanism is vitiated by the discovery that identical surface form between specimens from Europe and America was accompanied by slight differences in anatomy or specific differences in cone structure.

From Moses' account of the spread of the passengers of Noah's ark to Matthew's recently published Climate and Evolution, many attempts have been made to explain the origin and migration of organisms. It has taken a long time for naturalists to realize that modern distribution has its key in ancestral distribution, or to discriminate the fluctuation of life zones from such very different seasonal phenomena as are displayed by the migratory birds. It would perhaps be better to eliminate the word migration altogether and use the term dispersal, since the criteria of voluntary and involuntary action are of extremely doubtful validity.

The time of origin of an organic type or assemblage, the place of origin, the area once occupied and the time of extinction or the area now occupied, are among the most important questions with which we have to deal. Obviously without the correct chronology such questions are insoluble, hence the importance of far flung correlations and the need for the most critical criteria for correlation.

Similar successions of fossil-bearing sediments in different areas naturally resulted in this correspondence being considered indicative of synchroneity. Huxley in his anniversary address to the Geological Society of London in 1862 was the first serious critic of this conception. He, as you know, proposed the term homotaxis for the alternative idea due to the necessity of taking into account the time consumed in the dispersal of organisms. Those who adopt the latter and apparently reasonable assumption sometimes take the position (E. Forbes, N. S. Shaler) that similarity of organic content, instead of being indicative of chronologic synchroneity, proves that the compared deposits could not have been contemporaneous. Conceding that this view grossly exaggerates the importance of the time element, it is to be noted that of

late there has been a tendency to deny altogether the validity of the homotactic viewpoint.

The question is vital in a consideration of past evolution, distribution, climatic conditions and paleogeography. It is also almost infinitely complex, and there are various underlying conceptions such as the rate of spread of different classes of organisms and the degree of cosmopolitanism reached by marine organisms during times of land emergence and of terrestrial organisms during times of submergence when the obverse records are largely wanting, that have a very important bearing. If the conditions, both geographic and topographic, which are predicted for the various Appalachian troughs or basins during Paleozoic time, are correctly interpreted, as there seems to be no reason for doubting, we are introduced to an environment which is special in the sense that it is not duplicated at the present time anywhere on the earth's surface so far as I can see. This being true the generalizations derived from the study of the overlaps and the rapid floodings of these Appalachian basins must be applied with great caution to other sets of conditions such as determined the broad seas of Jurassic, Upper Cretaceous or Eogene times.

If our present Coastal Plain margin were to take another dip beneath the ocean, would it be possible for the paleontologist of a million years hence to establish the synchroneity of deposits formed at the same time along our middle Atlantic and Gulf coasts or to differentiate these chronologically from such late Pleistocene shell marls as those at Wailes Bluff at the mouth of the Potomac or Simmons Bluff in South Carolina? I think it would be feasible, and am inclined to disagree with the universality of the statement (Ulrich) that for stratigraphic purposes the coarseness of the distinguishable chronologic units obviates the necessity of attempting to deal with the theoretically true time involved in dispersal. This may be perfectly true, however, of some of the Paleozoic transgressions over the base-levelled Appalachian troughs and also when dealing with marginal invasions around the borders of a single oceanic basin where the faunas have had time to become generally distributed.

Our conclusions usually do not rest upon irrefutable logic, however, and it is most important to determine by closer analysis the interlacing waves and ripples of dis-

persal of animals and plants that have been going on since the beginning of life—as well as the rapidity of radiation of different types of organisms. Paleogeography will be on a far less speculative footing when it rests on proof and not on authority.

I do not believe that we can safely generalize with our present stock of accumulated knowledge. Take a theoretical case of a transgression and assume that the rate of change of level amounted to a foot a century, which I suppose would be considered fairly rapid, and that the submergence amounted to 500 feet, the time involved would be 50,000 years. The Upper Cretaceous transgression represented by the Dakota sandstone and Benton involved perhaps twice as great a change of level, and disregarding any halts or oscillations of the strand it would still mean that 100,000 years were involved in the operation. Inevitably there would be changes in salinity and climate which must be reflected in the faunas. It seems to me that we must either admit a certain measure of validity of homotaxis in all except special cases or assume that the breaks between faunally distinct formations represent very great lapses of time. On the other hand changes in faunal facies in passing from a formation like the Onondaga to the Hamilton mean merely a change in local environment such as is, I imagine, responsible for most examples of recurrent faunas, so-called.

The question is also influenced by what the term fauna denotes. Does it mean the whole biota or only certain forms considered as typical. Certainly I should expect Belemnitella to spread more rapidly than the contemporaneous Exogyra, or an Echinoid more rapidly than a Pentremite. The varying vitality or organisms under adverse conditions, either as mature animals or in the larval state, is also a factor of great importance. Larval oysters are very intolerant under adversity while other sedentary molluscs have a much more hardy progeny. Another factor in distribution is the relative length of the free swimming larval stage in sedentary forms. There are wide limits of usage as to what characterizes a fauna and what are its critical members. Shall we rely on its more abundant dominant species, on the percentage of species common to another fauna of known age, to the first or the last appearance of certain forms, or shall we place the greatest weight upon the rarer short lived

types? It seems to me that no single rule of general application can be laid down. There should be no dogmatism! In general the broadly conceived species which are abundant, are long ranging and of less value than the perhaps rarer more restricted types. One type of organism may be much more valuable than another. I should regard the active Zeugledon of the open sea as a much more critical indication of Upper Eocene age than a dozen species of Mollusca. Similarly I should regard the sea lizards of the Upper Cretaceous or fishes like Pycnodus as of much more diagnostic value than species of Exogyra or Inoceramus. The wider removed the areas to be correlated, the more important are the geographically wide ranging and geologically restricted forms and the greater the importance to be attached to their initial appearance.

Progress depends on research, as even an outcrop chaser in Oklahoma would probably admit, but research is about as much abused a term as culture. Research to the neophyte at the university, particularly in current biologic and psychologic investigation, consists in "having a problem" and I often wish that the Board of Health classed "having a problem" along with other communicable diseases and would quarantine its victims.

True research does not depend on subject matter *but on method* and the invidious distinction and discussions of pure and applied science would have no point were it not for the pragmatic individuals, false and mercenary ideals and superficial Burbank methods that characterize so much of applied science.

I should wish to depreciate the tendency, rampant throughout the world, and accelerated by war conditions, to seek a justification for research as a means toward some economic end. If the elucidation of earth history and the origin and evolution of life on the globe are not of prime importance as ends in themselves; if the whence and the why and the whither are not supreme, then indeed has our lot fallen among evil days.

Research is, I suspect, a dangerous subject for discussion before a body of men the majority of whom are connected with a great Federal Bureau. There are so many very necessary and commendable public services crying for accomplishment, and there is so much justification for the pious wish to give the people what they think they

want, that it is not to be expected that the pragmatist and the idealist will contentedly lie down together like the proverbial lion and lamb, or that the Survey will ever lack for critics or defenders. Without posing as either may I not venture to hope that research will constantly increase in both quality and amount, and that the day will speedily arrive when a first rate paleontologist can command as large an income in the successful practice of his profession as he can in an administrative position.

I have, I fully realize, inflicted upon you to-night a few rather poorly articulated and in some cases trite illustrations. A large subject hastily presented always leads to half truths, unless elaborated in much greater detail, and I can only hope that those who follow me in the series will display a greater competence than I have done.

Johns Hopkins University,
Baltimore, Maryland.

## Art. II.—*Comanchean Formations underlying Florida*; by E. H. Sellards.

During the latter part of 1917 the Florida Geological Survey received through the courtesy of Mr. H. B. Goodrich, a very important set of well samples from a deep well then recently completed by the Dundee Petroleum Company in Sumter County, Florida. Early in 1918 a few of the samples from this well, in which foraminifera were abundant, were forwarded by the writer to Dr. T. W. Vaughan of the United States Geological Survey by whom they were referred to Dr. Joseph A. Cushman. The foraminifera of these samples indicated, according to Dr. Cushman, the presence of Comanchean formations in this well. Subsequently Dr. Cushman undertook for the State Survey a study of the cuttings from some fifteen wells in Florida, and has now published the results of his study.[1] The location of the wells from which samples were obtained is indicated on the accompanying sketch map (fig. 1).

In nine of the wells Comanchean fossils were recognized. These are numbers 2, 3, 4, 5, 7, 8, 11, and 15 as shown on the map. Numbers 6, 9, and 10, in which Comanchean fossils were not found, are shallow wells, from 113 to 190 feet in depth, terminating in the Eocene formations. Well number 12, at the north side of Lake Okeechobee, was represented by samples to the depth of only 500 feet; number 13, at Boca Grande, is represented by but one sample in which no characteristic fossils were found; number 14, at Ft. Myers, from which no Comanchean fossils were obtained, is represented by a series of samples submitted by the driller as representing the formations to the depth of 950 feet. Examining the results as a whole it is seen that fossils of the Comanchean formations were recognized in all wells of considerable depth from near Tallahassee in West Florida to Cocoa and Tiger Bay somewhat south of the center of peninsular Florida. In southern Florida these formations, although present as indicated by the well on the Florida Keys (well No. 15), lie at a much greater depth than in Central Florida.

Owing to the relatively small number of samples

[1] Fla. Geol. Survey, 12th Ann. Rpt., 1919.

obtained from some of the wells, together with the often imperfect preservation of the fossils, the minimum depth to the top surface of the Comanchean formations is fre-

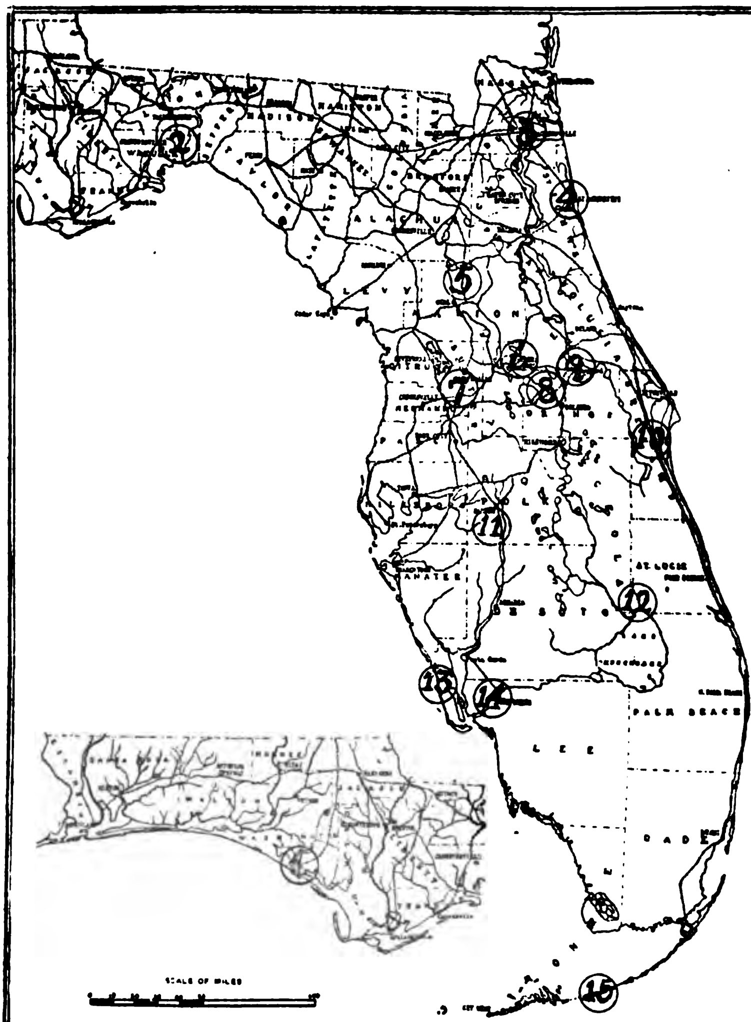


FIG. 1. Sketch map indicating location of wells.

quently difficult to determine. Nevertheless, approximate results are obtained by indicating the depth at which fossils of these formations are first recognized. In the

well near Tallahassee (well No. 2) Comanchean fossils are recognized at the depth of 325 feet, although the formation may extend much nearer the surface. The elevation at this well is 20 or 25 feet above sea-level. At Jacksonville, well No. 3, Comanchean fossils appear at 820 feet. Here again the formation may extend to a higher level, although not above the 550-foot level as samples from that depth contain Eocene fossils. The elevation at this well is 10 or 15 feet above sea-level. In wells number 4 to 11, located in central peninsular Florida, the Comanchean, when recognized, is found coming to a much higher actual level than at Jacksonville. At Anthony in Marion County, the Comanchean is recognized in the 110-foot sample (well No. 5). The ground level at this well as indicated by the topographic map is about 80 feet above sea. Hence, the Comanchean here comes to within about 30 feet of present sea-level. At Apopka, well No. 8, Comanchean fossils were found in the 115-foot sample. According to levels obtained from the Atlantic Coast Line Railway, the depot at Apopka is 125 feet above sea, and the well is said by Mr. Hull who preserved the sample, to be about 8 or 10 feet above the depot. From this approximate data it appears that the Comanchean at this place rises somewhat above sea-level. The samples from two wells at this place contain phosphate pebbles to the depth of about 220 feet. Since the Comanchean is not observed to contain phosphate pebbles in any of the other wells it seems probable that the phosphate pebbles had fallen from a higher level and that the samples are thus mixed in both of the wells to about that depth, notwithstandng that casing was placed in one of the wells at 117 feet and in the other at 127 feet. If the mixing of samples is due merely to material falling in from above, the observations as to the level of the Comanchean formations are not thereby affected. Farther to the south, at Tiger Bay (well No. 11), the Comanchean is first recognized at 550 feet, the surface elevation at the well being probably between 125 and 150 feet above sea. On the Atlantic Coast, at St. Augustine (well No. 4), the Comanchean is recognized at the depth of 440 feet and may extend somewhat nearer the surface. It is thus seen that in central peninsular Florida the Comanchean formations, as identified on the basis of these fossils, rise almost to present sea-level, possibly above in places.

From this central area they dip slowly to the east, lying at only a moderate depth on the Atlantic Coast at St. Augustine. To the northeast they dip more rapidly as indicated by the well at Jacksonville, while to the south from the central part of the peninsular they likewise dip very appreciably.

In a paper published in the Twelfth Annual Report of the Florida Survey the writer has sought to use the Eocene formations as an index to structural conditions in peninsular Florida. In this paper the data on the Eocene obtained by Cushman in connection with his study of the well samples is supplemented by data from a number of other wells of which records and samples have been obtained from time to time. From these data it is shown that there is a large belt extending entirely across north Central Peninsular Florida in which the Eocene formations lie either above sea-level (west side of the peninsula) or at from 100 to 200 feet below sea-level (east side of the peninsula). To the north the Eocene formations apparently dip very slightly; while to the east the dip is somewhat greater. To the northeast as indicated by the wells at Jacksonville the dip is pronounced. Likewise in passing to the south and southeast from north-central peninsular Florida the dip in the formations is quite appreciable. As early in 1881, Dr. E. A. Smith indicated in a paper and sketch map published in this Journal, that approximately the western half of the Floridian land mass is submerged to a shallow depth below sea-level.[2] This conclusion has been supported by subsequent studies and in addition there has been gradually developed the knowledge of a more complicated structure involving recognition of a broad dome centered toward the west side of the north central part of the peninsula. The anticlinal structure of the Floridian peninsula as a whole has likewise been long recognized, and the structure here referred to may possibly be characterized as a slight doming in the larger structure. The abruptly terminating margins of the Florida land mass, at or near the 100-fathom line in the Atlantic Ocean and in the Gulf of Mexico, suggest faulting along these lines by which the land mass has been lifted as a block as well as folded as a large geo-anticline.

[2] Vol. 21, pp. 292-309. 1881.

University of Texas,
Austin, Texas.

ART. III.—*Studies in the Cyperaceæ;* by THEO. HOLM. XXVII. Notes on *Carex podocarpa* R. Br., *C. Montanensis* Bail., *C. venustula* Holm, *C. Lemmoni* W. Boott, and *C. æqua* Clarke. (With 12 figures drawn from nature by the author.)

## *Carex podocarpa* R. Br.

When Robert Brown was engaged in identifying Dr. Richardson's arctic plants, a specimen of the genus *Carex* attracted his attention on account of the nut being stipitate; upon this specimen, which was rather immature, he established the species *C. podocarpa.* At that time the structure of the nut in *Carex* was but very imperfectly known, since most authors confined themselves to describing the structure of the perigynium (utriculus) alone. Otherwise the specimen showed no character of particular interest, and the diagnosis presented by Robert Brown is very brief. By Boott the specimen became illustrated in Hooker's Flora Boreali-Americana (vol. **2**, tab. 224), and this figure together with the diagnosis does enable us to get some idea of the plant, of the species it was intended for. And although being a small, rather inconspicuous plant, *C. podocarpa* has nevertheless been accepted, and not infrequently so, as identical with such stately species as *C. macrochæta* C. A. Mey, and *C. spectabilis* Dew.[1]

The fact that very recently[2] the species has been redescribed and attributed such characters as the original plant never possessed, may render the following supplemental note acceptable. Naturally the name of the author, who proposed the species, has carried great weight, and now for nearly a century the species has been faithfully accepted, figuring prominently in lists of plants from the boreal regions of North America and Eastern Asia. No author, so far, has ever suspected that *C. podocarpa* was described and named—but of course with a different name—before Robert Brown proposed it as a new species. However, the material brought together of what has been supposed to be *C. podocarpa* has proved

[1] Macoun, John: Catalogue of Canadian plants, Part IV, p. 149, Montreal, 1888.

[2] Kükenthal Georg: *Cyperaceæ—Caricoideæ* in A. Engler "Das Pflanzenreich, Leipzig, 1909.

very unlike the species so named, and, indeed, by no means conspecific; moreover the recently published diagnosis by Kükenthal (*l. c.*) deviates in several respects from the original as well as from the figure, cited above.

The original diagnosis of *Carex podocarpa*[3] reads: "spica mascula solitaria, femineis binis pendulis oblongis, stigmatibus tribus, fructibus ellipticis brevissime rostellatis integris lævibus acheniisque pedicellatis, foliis caulinis inferioribus brevioribus lanceolatis. Brown M. S." The species is described together with *C. capillaris* and *C. limosa* in a separate section: "spicis sexu distinctis, mascula solitaria, femineis omnibus pedunculatis." According to our friend, the late Mr. C. B. Clarke at Kew (in litteris April 16, 1902), the figure by Boott (*l. c.*) is accurately drawn, and shows the specimen collected by Richardson n. 370, upon which Robert Brown founded the species. The species is phyllopodic and stoloniferous; the nut is stipitate. But in accordance with Kükenthal (*l. c.* p. 410) *C. podocarpa* is aphyllopodic "*Scitæ aphyllopodæ,*" and his description calls for a larger plant with two to three pistillate spikes, the basal remote, born on a long, very slender peduncle. No mention is made of Boott's figure, and among the specimens examined, reference is made to Richardson's plant (n. 370), and, furthermore, some specimens collected by J. Macoun in Alberta: Sheep Mt., Watertown Lake (n. 10731).

These specimens from Alberta average from thirty-five to forty-five cm. in height; the number of pistillate spikes is from three to six, but mostly three; the nut is stipitate. But characteristic of these specimens is the dimorphic structure of the shoots, some being purely vegetative, others purely floral, the latter bearing leaf-sheaths with very short blades. They illustrate, in other words, the structure by Elias Fries defined as "aphyllopodic." We have previously called attention to this peculiar structure of shoots noticeable in several species of *Carex*,[4] but since the structure has been misunderstood or not considered of sufficient importance as a morphological character, judging from a number of instances in the

[3] Plants from the Appendix to Captain Franklin's narrative. London, 1823. (The miscellaneous botanical works of Robert Brown, vol. 2, p. 517, London, 1867.)

[4] Holm, Theo: Segregates of *Carex Tolmiei* Boott. (This Journal, vol. 14, p. 418, December, 1902.)

monograph presented by Kükenthal, it may be appropriate to insert some quotations from the paper of Elias Fries.[5] Having described briefly the cæspitose and stoloniferous types of growth Fries also points out the difference in foliage at the base of the flowerbearing stem or culm, viz.: "Alia memorabilis differentia posita est in culmi pede; hic vel cingitur vaginis aphyllis (*Aphyllopodæ*) vel vaginis omnibus foliiferis imis licet emarcidis (*Phyllopodæ*). Quanti momenti hæc differentia est, collatis *C. stricta* et *C. acuta, C. cæspitosa* et *C.* vulgari, facile videbis."—*Aphyllopodic* are for instance *C. maritima, C. Lyngbyei, C. cryptocarpa, C. stricta, C. cæspitosa,* etc., while the following are phyllopodic: *C. prolixa, C. acuta, C. rigida,* etc. It deserves notice that besides the species with monopodial ramification (*C. laxiflora* cet.), which are all "aphyllopodic," not a few species of those with sympodia belong to this same category (*C. Tolmiei, C. angustata, C. spectabilis* cet.). Such phyllo- and aphyllo-podic species are readily to be distinguished from each other, inasmuch as the character is constant; low forms of the aphyllopodic *C. macrochæta* exhibit in this wise an entirely different aspect from the phyllopodic *C. ustulata,* with which such dwarfish forms have often been confounded. And no instance has, so far, been observed where an aphyllopodic species might change its habit so as to become a phyllopodic variety, or vice versa. In other words the phyllopodic *C. podocarpa* R. Br. as depicted by Boott cannot positively be conspecific with the plant collected by Macoun, which is aphyllopodic. The stipitate nut is not a character possessed by *C. podocarpa* alone, but recurs in several species of the *Aeorastachyæ,* when examined at young stages, furthermore in some of the *Melananthæ* (fig. 5). Finally there is another plant which has also been referred to *C. podocarpa* by Kükenthal (*l. c.*), and this plant was collected on the northwest coast of this continent by Seemann (n. 2207); it is a phyllopodic species, and by C. B. Clarke identified as *C. ustulata* Wahlenb.

Several years ago when engaged in identifying some large collections of *Carex* mainly from Alaska, and British Columbia, we were unable to find any specimen that might represent the true *C. podocarpa* R. Br.,

[5] Fries, Elias: Synopsis *Caricum* distigmaticarum, spicis sexu distinctis, in Scandinavia lectarum. (Bot. Notiser, p. 97, Lund, 1843.)

although there were some, which were identical with specimens named so by other authors. However, to make certain about this matter we asked C. B. Clarke at Kew for assistance, and it is through his kindness that we are able to offer the following, valuable information, written in a letter dated April 16th, 1902: "I find that Richardson n. 370 is a single culm (the utricles very young), and Boott has noted on it that it is the whole material for the species. And Arthur Bennett has named this type-piece *C. rariflora* Smith: and so it is! Richardson collected a quantity of *C. rariflora* and this '*podocarpa*' looks certainly a fragment out of the rest of his *rariflora,* which was sent up to Brown (at the British Museum) to draw up his list upon. The Kew Index and other authors cite *C. rariflora* Smith Engl. Bot. v. **4** (1828) p. 100; and if this were the true original citation, the name *podocarpa* would have priority—but I find *C. rariflora* Smith (in Sowerby) Engl. Bot. v. **35** (1813) t. 2516 and there may very possibly be names anterior to this." In comparing Boott's figure (*l. c.*) with a young specimen of *C. rariflora* Sm. there can be no doubt about the correctness of the identification proposed by the botanists at Kew. But if we compare the diagnosis of *C. podocarpa* submitted by Kükenthal (*l. c.*), and founded upon three plants of very distinct habit and by no means conspecific, the result is, of course, confusion. For even if Robert Brown's *C. podocarpa* had not been described before, it could never be understood as representing an aphyllopodic species, as claimed by Kükenthal, and confounded with the plant collected by Macoun (*l. c.*).

### *Carex Montanensis* Bail.[6]

This is the name of the species collected by Macoun (*l. c.*). It is a member of the *Melananthæ* Drej., and very characteristic by the several, two to six, long-pedunculate, drooping, dark-colored pistillate spikes, and by the relatively tall, aphyllopodic culm; the latter character is not, however, mentioned in the diagnosis; furthermore may be stated that the scales of the staminate spike are light reddish-brown with green, not excurrent midrib, while those of the pistillate are deep-purple to black with no midvein visible; utriculus is purplish-spotted, with the beak almost entire, spinulose, and with

[6] Bot. Gazette, p. 152, May, 1892.

two very distinct marginal nerves; the nut is triangular, much smaller than the utricle, and stipitate; there are three stigmata.

The specific name is unfortunate, as are geographical, specific names in general; the species, originally established upon a plant from Montana, has since been collected in Idaho, in Alberta, British Columbia, and Yukon.

### *Carex venustula* Holm[7] (figs. 1-5).

This species is a near ally of the preceding, but is readily distinguished by the long leaves of the vegetative shoots, and by the pistillate scales being obtuse to aristate, much shorter than the perigynium, which is minutely granular above.

By Kükenthal (*l. c.* p. 412) these two species are considered identical with *C. spectabilis* Dew., together with the phyllopodic *C. microchæta* Holm; beside that a part of the specimens of the former (*C. Montanensis*) has been referred to *C. podocarpa.*

The section "*Scitæ*" Kükenth. seems untenable, since it is characterized as containing only aphyllopodic species; but among the species referred to this section we find the following phyllopodic: *C. podocarpa* R. Br., *C. microchæta* Holm, *C. nesophila* Holm, and *C. littoralis* Schweinitz.

By eliminating *Carex podocarpa* R. Br., so far entirely misunderstood, the identification of several northwestern *Carices* becomes facilitated, and to no small extent. *Carex macrochæta* C. A. Meg. at its various stages, and especially the younger ones, cannot possibly be confounded with *C. ustulata* Wahlenb., a phyllopodic species; and *Carex spectabilis* Dew. with the scales merely mucronate, of a lighter color, is sufficiently distinct from *C. ustulata* Wahlenb. as well as from *C. macrochæta* C. A. Mey. These three species are actually those that have hitherto been confounded with the troublesome *C. podocarpa* R. Br. With respect to *C. Montanensis* Bail., and *C. venustula* Holm, both aphyllopodic, these cannot be considered conspecific with the phyllopodic *C. microchæta* Holm; neither can the phyllopodic *C. nesophila* Holm be looked upon as representing a variety (*subrigida* Kükenth.) of the aphyllopodic *C. macrochæta* C. A. Mey.

[7] Holm, Theo: New or little known species of *Carex.* (This Journal, vol. 17, p. 304, April, 1904.)

*Carex Lemmoni*, W. Boott (figs. 9-12).

Although an excellent, in several respects quite remarkable species, and well described by the author William Boott,[8] *Carex Lemmoni* has for the last thirty years been identified and distributed under another name: *C. ablata* Bail. The error was detected by C. B. Clarke (in litteris), who then wrote a diagnosis, and gave a name to the so-called *C. Lemmoni: Carex æqua;* in accordance with Clarke, *C. æqua* is the plant which by W. Boott was enumerated as *C. fulva* var. *Hornschuchiana* in S. Watson's Botany of California (vol. **2**, pp. 228, 250), and also the plant called *C. Lemmoni* by L. H. Bailey in his Preliminary Synopsis of North American *Carices*.[9] By Kükenthal (*l. c.* p. 666), *C. Lemmoni* (non W. Boott) and *C. serratodens* (non W. Boott) are considered identical, and the name *serratodens* is given the preference; nevertheless among the specimens cited by Kükenthal is Bolander's (n. 4995), which is *C. albida* Bail., a near ally of the true *C. Lemmoni,* beside C. F. Baker's (n. 811), which is *C. æqua* Clarke. It is hardly necessary to state that the diagnosis does not cover either *C. serratodens* W. Boott nor *C. albida* Bail. And by this same author (*l. c.* p. 558) *C. ablata* Bail. has been made a variety of *C. luzulæfolia* W. Boott with forma *albida* (Bail.) Kükenthal (*C. albida* Bail.). In other words W. Boott should have proposed three species of *Carex: luzulæfolia, serratodens* and *Lemmoni,* constituting an assemblage of such confusion!—However the fault depends only upon the fact that recent authors have not consulted the literature, or they have not interpreted Boott's diagnoses in the proper way. It is really difficult to understand how Boott's *C. Lemmoni* could ever be misunderstood, and for so long a time, although a considerable material became collected from a number of stations, especially along the Pacific coast from Southern California (fide S. B. Parish) to British Columbia, in view of the fact that it was described very minutely; while the establishment of the species *ablata* Bail. merely rests on some incomplete, brief remarks:[10] "*C. frigida* of American botanists, not Allioni. Distiguished from *C. frigida* chiefly as follows: Culm stiffer and more erect: leaves broader and firmer, usually shining, commonly shorter: staminate

[8] Boott, William: Notes on *Cyperaceæ* (Bot. Gaz. vol. **9**, p. 85, 1884).
[9] Proceed. Am. Acad., p. 112, 1886.
[10] Bailey, L. H.: Notes on Carex IX. (Bot. Gaz. vol. **13**, 1888).

spike smaller, nearly sessile: pistillate spikes shorter and thinner, lighter colored, shorter stalked, the upper 2 or 3 usually aggregated and sessile or very nearly so: scales obtuse, usually shorter: perigynium not so long and slender-beaked. Western Territory."—No mention is made of the probable affinity with Boott's *C. luzulæfolia,* or of the possible identity with his *C. Lemmoni.* This seems the more curious when this same author (L. H. Bailey) in the following year proposes his *C. albida* as an ally of *C. luzulina* Olney,[11] with no reference to *C. luzulæfolia* Boott or to *C. ablata* Bail., not speaking of the true *C. Lemmoni* W. Boott.

Having had access to a number of specimens identified by Professor Bailey himself as representing *C. ablata* we naturally depended on the correctness of the determination. But some years ago, when called upon to name some Californian *Carices,* we came across the so-called *C. Lemmoni,* and being unable to identify this by means of comparing the original diagnosis, we submitted the specimens to C. B. Clarke. Again it is through the kindness of this excellent botanist that the difficulty became removed, and we were informed that Boott's *C. Lemmoni* had been sent to Kew as *C. ablata* Bail., while the so-called *C. Lemmoni* was an undescribed species for which Clarke proposed the name *æqua;* it was based upon material collected by C. F. Baker in California: San Mateo (n. 811).

To prevent future difficulty regarding the identification of *C. Lemmoni* W. Boott we might reprint the original diagnosis: "Cæspitosa. Culmis 2 ped. altis, latere ½ lin. latis, obtusangulis lævibus, vaginis omnibus foliiferis, infra medium foliatis. Foliis lineari-lanceolatis, apice subulato triquetris, erectis, vaginatis, 1½ lin. latis, culmeis 3-4, sterilibus 6-10 poll. longis. Bracteis foliatis vaginatis, spiculis longioribus, culmis brevioribus. Vaginis ½-1¼ poll. longis. Ligula oppositifolia obtusa. Squamis pallide-ferrugineis, membranaceis, margine hyalino, oblongo-obovatis, obtusis, mucronatis, perigynia æquantibus. Perigyniis ferrugineis, membranaceis. lævibus, triquetro-oblongis, basi acutis, acuminato-rostratis, 1¾ lin. longis. ½-¾ lin. latis. rostro bidentato margine serrato dentato. nervatis. Achenium atro-castaneum, triquetro obovoideum, basi productum apice obtusum

[11] Mem. of Torrey Bot. Club, vol. 1, No. 1, 1889.

stylo æquali apiculatum. Stigm. 3. I. G. Lemmon 1875."

Some few remarks may be added to this diagnosis, viz: The culm is phyllopodic, and the number of spikes, the pistillate, quite variable; there is only one sessile staminate spike, and with respect to the pistillate the uppermost two or three are situated close to the base of the terminal, the staminate, while the lower ones are remote; the number of pistillate spikes averages from two to six, five being the most frequent.[12] Furthermore the scales of the pistillate spikes (fig. 10-11) are mostly obtuse, and fringed along the upper margin, but in some specimens the midrib was extended so as to make the scale mucronate; however such mucronate scales were observed in spikes of which some of the other scales were simply obtuse. In none of the mature specimens examined did we observe any case where the scales were of the same length as the perigynia; they were constantly shorter than these (fig. 11). The perigynium (fig. 12) is generally very narrow, and spinulose along the margins from the middle of the body to the apex of the beak. Finally in most of the specimens from Mount Paddo, Washington, kindly presented to the writer by Mr. W. N. Suksdorf, the basal leaves were shorter and more spreading, rather than erect, the bracts subtending the spikes were shorter and narrower, and the color of the scales much darker than in typical specimens. A similar dark color of the scales and perigynia is, also, characteristic of the Californian plant in accordance with S. B. Parish, who has contributed a very instructive paper dealing with *Cyperaceæ* from Southern California.[13]

*Carex Lemmoni* W. Boott is a member of the grex: *Stenocarpæ,* and is allied to *C. luzulæfolia* W. Boott, a very robust plant with broad, spreading leaves (basal) and thick spikes. Of this species we have proposed a variety *strobilantha* of which the perigynium is nearly sessile, broadly ovate to almost globose, terminated by a very distinct, bidentate beak. It is this plant which C. B. Clarke has described under the name *C. pseudojapo-*

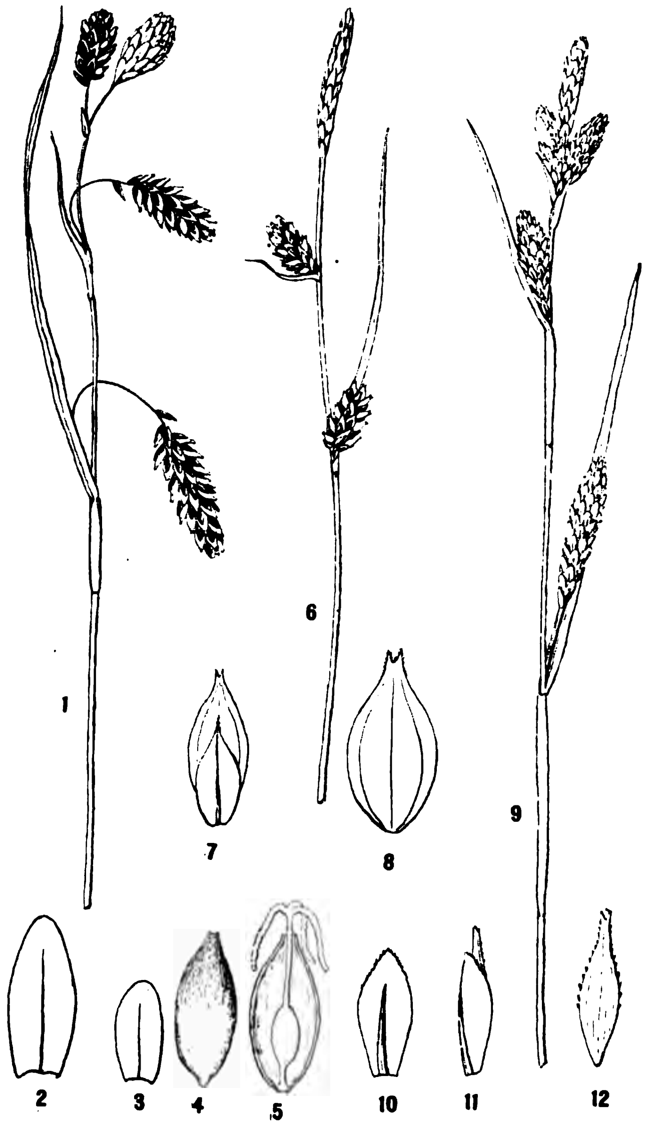
[12] As to the number of pistillate spikes we found in fifty-four specimens from British Columbia, Vancouver Island, Washington and Oregon:

18 specimens with five pistillate spikes.
14 specimens with four pistillate spikes.
14 specimens with three pistillate spikes.
6 specimens with two pistillate spikes.
2 specimens with six pistillate spikes.

[13] Bull. South Calif. Acad. Science, March, 1904.

*nica,*[14] stating that the affinity is with *C. gansuensis* Franchet.

*Carex albida* Bail. appears to be a distinct species,




intermediate between *C. luzulæfolia* and *C. Lemmoni* W. Boott. It has phyllopodic culms like the others, but it is

[14] Clarke, C. B.: New genera and species of *Cyperaceæ*. (Bull. miscell. inform. Roy. Bot. Garden, Kew. Addit. Series VIII, London, 1908.)

much more slender in all respects, and of a very light color, as indicated by the name.

*Carex æqua* C. B. Clarke (figs. 6-8).

The diagnosis[15] of this new species reads as follows: "Rhizomate ligneo horizontali; culmis 5-6 dm. longis, gracilibus; foliis 2½-3 m. m. latis; spicis 3-5, sessilibus, sparsis, terminali mascula sessili; stylo trifido; utriculis (rostro incluso) vix 3 m. m. longis, ellipsoideis, trigonis, levibus glabris.

*C. fulva* var. *Hornschuchiana* W. Boott in S. Watson's Botany of California II, p. 228, 250. *C. Lemmoni* L. H. Bail., Proceed. Am. Acad. p. 112, 1886 *non* Boott.

*C. Lemmoni* W. Boott in Coulter's Bot. Gazette IX, 1884, p. 93, est planta cæspitosa foliis lineari-lanceolatis. California: San Mateo, Baker n. 811."—To this diagnosis may be added that the strong, horizontal rhizome is stoloniferous, covered with dark reddish-brown, scale-like leaves; that the staminate spike is sometimes pedunculate, and gynæcandrous; that the bract of the lowest spike is sheathless, with the blade overtopping the male spike; that the scales of the pistillate spikes are aristate, the arista scabrous; that the spreading perigynia are obscurely 6-8 veined, and terminated by a short beak, which is bidentate, and finely spinulose (figs. 7-8).

The species has, so far, only been collected in California: San Mateo County, and Marin County, Mount Tamalpais, by C. F. Baker, W. N. Suksdorf and C. V. Piper.

The affinity is with *C. diluta* M. Bieb. of the grex: *Spirostachyæ.*

EXPLANATION OF FIGURES.

FIG. 1. Inflorescence of *Carex venustula* Holm, natural size. Specimen from Chistachina River, lat. 63, between Cook inlet and the Tanana River, collected by E. F. Glenn.

FIG. 2. Scale of staminate spike of same; enlarged.

FIG. 3. Scale of pistillate spike of same; enlarged.

FIG. 4. Perigynium of same; enlarged.

FIG. 5. Same opened, showing the stipitate nut; enlarged.

FIG. 6. Inflorescence of *Carex æqua* Clarke, natural size. Specimen from Crystal Springs, San Mateo County, California, collected by C. F. Baker.

FIG. 7. Scale and perigynium of same; enlarged.

FIG. 8. Perigynium, fully matured of same; enlarged.

FIG. 9. Inflorescence of *Carex Lemmoni* W. Boott; natural size. Specimen from Chilliwack Valley, British Columbia, collected by J. M. Macoun.

FIG. 10. Scale of pistillate spike of same; enlarged.

FIG. 11. Scale and perigynium of same, side view; enlarged.

FIG. 12. Perigynium of same, front view; enlarged.

Clinton, Md., February, 1919.

[15] Ibidem.

ART. IV.—*On Atavism and the Law of Irreversibility*, by AGNES ARBER, D.Sc.

In a paper recently read before the Linnean Society,[1] I have drawn attention to a certain minor principle of evolution—the 'Law of Loss'—deduced from considerations relating to the comparative morphology of living plants. I have defined the expression 'Law of Loss' as indicating the "general rule that a structure or organ once lost in the course of phylogeny can never be regained; if the organism subsequently has occasion to replace it, it cannot be reproduced, but must be constructed afresh in some different mode."[2] The 'Law of Loss' corresponds in fact to a part of the broader principle recognized by Dollo[3] under the name of the 'Law of Irreversibility,' though I was unacquainted with the Belgian Professor's work on the subject at the time when I formulated the Law of Loss. Since the paper in question was written, my attention has been called to a passage in Professor J. Bretland Farmer's "Plant Life," in which a principle is enunciated also covering part of the ground of Dollo's Law. In the chapter dealing with the relating of plants to water, the following sentences occur: "It is a singular fact that when a species or race has once exhibited a tendency towards the loss or atrophy of an organ, e. g. the leaf, the descendants commonly appear unable to check it. If any of them vary in such a way as to increase their green surface, this is effected not by enlarging their diminished leaves, but by flattening and specialising some other organ."[4] We may—perhaps rather crudely—interpret this suggestion as indicating that the path of degeneration represents a downward slope on which progress, once begun, con-

[1] The 'Law of Loss' in Evolution. Read 7th Nov. 1918 (to appear in Proc. Linn. Soc. Lond., 1919).

[2] This law applies only to *actual* losses and not to *apparent* losses due to the interpolation of inhibiting factors; the necessity for this distinction has been pointed out to me by Miss E. R. Saunders.

[3] Dollo, L., Les lois de l'évolution. Bull. Soc. Belge de géol. paléont. hydrol., 7, Procès-verb., Séance du 25 juillet, 1893, pp. 164-166. See also a recent paper by Dr. B. Petronievics in which Dollo's memoirs on the subject are analysed in detail (Sur la loi de l'évolution irréversible, Science Progress, vol. 13, pp. 406-419, Jan. 1919).

[4] Another passage bearing on the same subject may also be cited (p. 113): "And there are a very large number of instances, of the most varied kind, which indicate that when an organism has once modified its constitution so as to exhibit any special trend, the chances are all in favour of advance along the new lines, and very slightly indeed in favour of a return to the old ones."

tinues automatically. Farmer's conception of the process of atrophy is interesting in connection with a passage in "The Origin of Species" expressing the difficulty of accounting for the complete loss of rudimentary organs. "After an organ has ceased being used," Darwin wrote, "and has become in consequence much reduced, how can it be still further reduced in size until the merest vestige is left; and how can it be finally quite obliterated. It is scarcely possible that disuse can go on producing any further effect after the organ has once been rendered functionless. Some additional explanation is here requisite which I cannot give." It seems fairly obvious that any attempt to explain away this difficulty on the Natural Selection hypothesis must be artificial and inadequate, but Dollo's principle, and especially that particular aspect of it at which Farmer has independently arrived, at least brings the phenomenon under a general law.

It has recently been suggested to me by Dr. E. G. Salisbury that resupinated leaves, such as those of *Allium ursinum, Alstroemeria,* etc., provide a clear instance of the tendency on the part of the plant to continue along any path on which it has once started. He points out that we must suppose, on grounds of comparative anatomy and morphology, that the Alstroemerias originally had normally orientated leaves. The first formed leaves are held in the profile position, and it seems that the plant, having begun to turn its leaves, has found it easier to go on turning them than to turn them back, despite the fact that the continuation of the original line of evolution involves the differentiation of the morphologically lower side as palisade, and the original palisade as spongy tissue. I have been interested to find that Salisbury's mode of visualising the process of leaf inversion, as a commitment on the part of the plant to a course from which there is no turning back, receives independent confirmation in Dr. Lindman's[5] description of the peculiar behaviour of a certain *Bomarea* in which the leaves are invariably resupinate. He observed that the mature shoots of this plant were often so placed that the resupinate leaves would be 'upside down,' i. e., with their *morphologically* upper side again actually uppermost. But such leaves were invariably found to return to their

[5] Lindman, C. A. M., Zur Morphologie und Biologie einiger Blätter und belaubter Sprosse, Bihang Svenska Vet. Akad. Handl., 25, Afd. III, No. 4, 63 pp., 20 text figs., 1899.

habitual orientation, not however by losing their usual twist, but always *by adding a second torsion above the first*. This shows, as Lindman points out, how inveterate (eingewurzelt) this habit has become; in other words it demonstrates that when the plant can reach the same goal either by retracing its steps, or by pursuing its adopted path to a further point, it has an overwhelming bias towards the latter course.

Dollo's Law has been subjected to considerable criticism, especially by the late Professor Errera[6] on the botanical side, and recently by Dr. Boulenger[7] as a zoologist. I am not competent to discuss Dr. Boulenger's arguments, since their appraisement demands a familiarity with vertebrate morphology which I do not possess; but I wish here to consider Errera's objections, as well as certain general considerations relating to animals and plants which have been held to militate against the Law of Irreversibility.

It may be stated, broadly, that the opponents of Dollo's Law regard it as disproved by the facts of 'reversion'—that is by cases in which a variation appears which is interpreted as an atavistic[8] 'throw-back' to an hypothetical ancestor, and in which some character since lost by the species makes a renewed appearance. It will be necessary to analyse Errera's criticisms—most of which conform to this type—in some little detail, since he claims that the instances he cites "suffisent à mon sens à réfuter la théorie de l'irréversibilité." The first phenomenon to which he points as evidence is not, however, a case of varietal reversion; it is the apetalous character of certain Caryophyllaceæ, Rosaceæ, etc., which he regards as a recurrence of "l'apétalie primitive des Angiospermes inférieures." But this apetaly cannot be treated as furnishing an exception to the Law of Irreversibility if the more modern view be accepted which holds that the

[6] I am indebted to Mr. C. Davies Sherborn and to Dr. G. A. Boulenger, for drawing my attention to Errera's criticism, which is contained in Une leçon élémentaire sur le Darwinisme, Recueil d'œuvres de Léo Errera, Bot. Gén., 2, pp. 163-268, 1909.

[7] Boulenger, G. A., L'évolution est-elle réversible? Considérations au sujet de certains poissons, Comptes rendus des séances de l'Académie des Sciences, 168, p. 41 (séance du 6 janvier 1919).

[8] In the present paper the word 'atavism' is used in a broad sense as synonymous with 'reversion'—a sense in which it is habitually used in both French and English non-scientific literature. The attempt to restrict it in genetics to those cases in which some character of a grandparent is repeated in his grandchild seems indefensible when it is remembered that 'atavus' means 'great-great-great-grandfather' and is also used in the general sense of 'ancestor.'

primaeval flower was of the eu-anthostrobilus type with a perianth. It is not necessary to labour this point, since Errera himself, at a later date, became disposed to regard the Ranales and Alismaceæ, rather than the Apetalæ, as primitive forms. And even if Errera's original view be accepted, this case, though it might be then interpreted as an exception to the 'Law of Irreversibility,' cannot be claimed as affecting the validity of the 'Law of Loss,' with which we are here more especially concerned.

The other examples which Errera cites are the occasional development of a fifth stamen in the normally four-stamened Scrophulariaceæ, and also the case of Heinricher's[9] curious "*Iris pallida* Lam, var. *abavia.*" In this *Iris,* by the selection of spontaneous variations, Heinricher obtained a form in which all six perianth members were alike and bearded, while there were six stamens instead of the normal three. This condition of the stamens was interpreted as an atavistic return to the type of androecium characteristic of the liliaceous stock from which the Iridaceæ are almost certainly derived, and in which there are *two* whorls of stamens, each with three members. These botanical cases may be compared on the animal side with Castle's[10] race of four-toed guinea pigs, which in this respect approached the ancestral form—presumably five-toed—more nearly than does the ordinary modern cavy, with its three-toed hind foot. The occasional appearance of three-toed colts has also been interpreted as an example of the reversionary recovery of lost organs.

It immediately becomes obvious, even on a casual scrutiny of these cases, that they possess one striking common characteristic—a charcteristic which seems to me to annul their significance as evidences of reversion. *They all relate to meristic variations in which certain organs, of which at least one already exists, suffer an increase in number.*

The case of *Iris pallida,* var. *abavia,* is particularly interesting from this standpoint and seems susceptible of a different explanation from that given by Errera. The six perianth members are all alike and all bearded, i. e.,

[9] Heinricher, E., *Iris pallida* Lam., *abavia,* das Ergebnis einer auf Grund atavischer Merkmale vorgenommenen Züchtung und ihre Geschichte, Biol. Centralbl., 16, pp. 13-24, 2 text-figs., 1896.

[10] Castle, W. E., The Origin of a Polydactylous Race of Guinea-Pigs, Carnegie Institution of Washington, Publication No. 47, pp 17-29, 1906. It should be noted that Castle does not describe this polydactylism as reversionary, but significance in this connection has been attributed to it by others, *e. g.,* Walter, H. E., Genetics, New York, 1913.

they appear to correspond to the outer perianth members of a normal flower, the three inner being absent. In other words, the abnormal form of perianth may be interpreted as due to the chorisis or *dédoublement* of the normal outer whorl. According to Errera, the six stamens are to be interpreted as incuding the three members of the outer whorl, and, in addition, the three members of that inner whorl which in the Iridaceae is normally suppressed. But it seems to me more reasonable to suppose that these three extra stamens are not the avatars of the defunct *inner* whorl, but have originated through the doubling of the members of the existing *outer* whorl; this suggestion has the advantage of postulating the same type of variation for both perianth and stamens. The important part which such secondary *dédoublement* may have played in the phylogeny of Angiosperms, has received full recognition from certain botanists who have tried to elucidate the history of the flower. Wernham[11] for instance holds that when indefinite stamen numbers occur within the Archichlamydeæ, but outside the more primitive families, this condition may perhaps be interpreted as due to secondary branching; the Opuntiales illustrate the extremest expression of this tendency to chorisis. In this connection it is possibly suggestive that—as Professor Punnett[12] has pointed out—in more than one of the rare cases in which the evolution of domestic races appears to have come about by the addition rather than the loss of factors, the interpolated factor is of such a nature as to cause reduplication. There may be some relation between such reduplicating factors and the chorisis to which we have just alluded.

The view that such forms as a *Linaria* with a five-chambered ovary,[13] a five-stamened *Stemodia*[14] or a four-toed guinea-pig, can be classed as 'reversions,' is also open to criticism on more general grounds. Such abnormalities are only claimed as atavistic if they happen to correspond to those forms which on morphological or palaeontological evidence we suppose to be ancestral. But other similar cases, such as the various well known examples of polydactylism in man, are passed over in

[11] Wernham, H. F., Floral Evolution; with particular reference to the sympetalous Dicotyledons, New Phyt., vol. 10, 1911 and vol. 11, 1912; see especially p. 111, vol. 10.

[12] Punnett, R. C., Mendelism, 4th Ed., p. 80, 1912.

[13] Crépin, F., Recueil de faits tératologiques, Bull. Soc. Roy. Bot. de Belgique, 4, pp. 276-8, 1 pl., 1865.

[14] Errera, L., *Pentstemon gentianoides* et *Pentstemon Hartwegi* Bull. Soc. Roy. Bot. de Belgique, 17, pp. 182-248, 1878.

silence in this connection. And yet it would seem as logical to treat them as a throw-back to some ancestor with supernumerary digits, as to suppose the same thing on precisely corresponding evidence in the case of a six-stamened *Iris*. And as Bateson[15] long ago pointed out—when dealing with just those types of numerical variation which have been claimed as exceptions to the Law of Irreversibility—a number of forms may occur through discontinuous variation, which, though equally perfect, cannot all be ancestral. Twenty-five years ago he wrote, "In the case of *Veronica* and *Linaria,* for example, a host of symmetrical forms of the floral organs may be seen occurring suddenly as sports, and of these, though any one may conceivably have been ancestral, the same cannot be supposed of all, for their forms are mutually exclusive."

There is no doubt that the hypothesis of reversion has too often been employed by morphologists in an uncritical spirit. To the students of variation and heredity we owe such lucidity and precision as the term has now gained, but yet biologists in general continue to use it as though it retained the nebulous quality which characterised it in Darwin's day. The only instances of genuine atavism[16] of which we have any knowledge are those which consist in the synthesis by hybridisation of some original form which has now become split into different races by loss of factors. But this is a totally different thing from the sudden appearance of so-called 'reversions' in cases where there has been no hybridisation. The desire to interpret phenomena on the reversion hypothesis may perhaps be traced to our natural mental craving for similitudes, which seems easily to lead to a failure to discriminate between analogy and identity. A new form may recall some ancestor, near or remote, but, if the Law of Irreversibility holds, it cannot be described as re-incarnating the qualities of that ancestor, except in the loose and metaphorical sense in which senility is described as 'second childhood.' It is probably not going too far to say that there is no such thing as the retracing of steps, either in the life of the individual or of the species: in the words of the old proverb, "The baked bread can never go back to the dough."

Balfour Laboratory,
Cambridge, England.

[15] Bateson, W., Materials for the Study of Variation, p. 76, 1894.

[16] The view that teratology reveals no undoubted case of reversion, is maintained by Demoor, J. Massart, J. and Vandervelde, E., Evolution by Atrophy, Int. Sci. Ser. vol. 87, 1899.

# ART. V.—*On a Possible Limit to Gravitation;** by FRANK W. VERY.

*General Statement of the Argument.*

It is assumed that gravitation acts by means of longitudinal. waves of alternate condensation and expansion in a universal medium which is also a magnetic medium, or "magnetic aura," composed of least parts, or magnetons, and which is subject to magnetic laws. Hence the gravitational wave at any instant is assumed to coincide with a magnetic equipotential surface and to follow in its progressions the curves of magnetic lines of force. Reasons are given for believing that the sphere of action of a given galactic mass of stellar material does not extend to infinity, but is contained within a definite aural "cell," or is limited by the vortical motions of a particular body of the universal aura which is independent of neighboring similar bodies, possibly because there is repulsion between them, so that interference is impossible. Speaking relatively, the galaxies are rather closely packed, in total disagreement with the sparsity of stellar distribution; and the galaxies have also much greater speeds than the relative speeds of the stars which compose them; but nevertheless the galaxies show hardly any appearance of collision or interpenetration—nothing which cannot be explained as variation in a general magnetic control.

In confirmation of this view may be cited Van Maanen's measures of the internal motions in Messier 101. The motions are *away* from the center, as if controlled by currents in the general medium, that is, these motions are not such as would be anticipated under the gravitational attraction of a central mass; and the flow appears to follow a law of the inverse *cube* of the distance which would be appropriate to a magnetic control. An attempt is made in this paper to devise a scheme of an atom, composed of least gravitative units, which shall be capable of performing these functions and of sustaining these relations to a general magnetic medium; and it is shown that gravitational waves having a frequency not

* This paper was presented at the Twenty-first meeting of the American Astronomical Society at Albany, August, 1917 (abstract in Publications of the Society, vol. 3, p. 335), but has been slightly modified since then.

far from that of a light-wave will account for the phenomenon, if circumscribed by a boundary; but that, otherwise, it is not easy to account for the action on mechanical principles. Hence it is concluded that, somewhat as the molecules of gases move in every direction among themselves, but are nevertheless controlled by the more general currents of the larger gaseous mass, so the individual motions of stars, or of lesser star clusters, are local and under the control of a more general movement of the body of aura which contains them.

According to the kinetic theory of gases, the pressure in a gas is that due to the momentum of the colliding molecules themselves as finally reflected from the containing walls of the enclosure. Without a limiting wall, the given mass of gas would expand indefinitely until its molecules ceased to collide and there would be no pressure. In a galactic mass, on the contrary, the individual stellar units do not collide, and the compression is not produced by the onward motion of the stellar "particles," or of their least component atoms; but it is produced in the containing medium by an internal mechanism within the atom itself, thus in an entirely different way. Nevertheless, as in the case of the theory of gases, it is difficult to see how there can be any *pressure* unless there is a retaining wall. Such a cell wall for the gravitational pressure is presumably a discontinuity in the aura produced by its vortical motion. Thus the aural cell may be likened to a gigantic "vortex-atom."

### *Gravitational Potential is a Strain in the Magnetic Medium caused by Electric Stresses.*

Until quite recently, one of the chief characteristics of gravitation has been supposed to be its universality. The attraction of large and small neighboring masses in the Cavendish experiment, the union of sun and planets, and of pairs of suns forming binary stars and separated by distances much exceeding those of the planets, all appeared to follow Newton's law with remarkable accuracy, and to be completely dissociated from every other form of physical force. No mode of screening this force has yet been discovered. If limitations to gravity exist, they must be sought in other ways.

Gravitational potential appears to consist in a state of strain set up in the magnetic medium through the inter-

action of waves in the medium which constitute the external gravitational field of the electronic movements which *are* matter. We admit that matter is first of all a circulatory movement of the two sorts of electricity (equivalent to an electric doublet) whose least components are everywhere accompanied by indefinitely extended and dynamically proportional vortices in the magnetic medium. It would appear, however, that, though no other than the magnetic medium can be concerned in the action, and though the gravitational lines of force are ultimately controlled by magnetic vortices, the gravitational forces are not to be confounded with magnetic forces.

Rutherford maintains that the positive electricity in an atom is a central mass of very minute size, placed there like a sun (as in Larmor's atom) to guide the orbital motions of the electrons. It has been supposed that the positive nucleus of an atom must be very minute, because collisions of alpha particles with them are infrequent; but contact in this case does not mean hitting the bull's-eye of a target. It means a sufficiently close juxtaposition of two interpenetrating fields of motion in the magnetic universal atmosphere to produce reaction; somewhat as the fields of force of light-rays everywhere interpenetrate without interfering, except where there is an exceptionally precise superposition of the extended fields, with similar, or with opposing phases, reinforcing the movement on the one hand, or destroying it on the other.

Now this assumption of central position is unnecessary; because Newton showed that the gravitational attraction of a spherical shell of matter is precisely the same as if all of the matter in the shell were concentrated at the center. Nor do we know just what it is that constitutes what we call an "attraction." A soap bubble is held together as one piece by a circumferential pressure everywhere centripetally directed. We explain this as the result of surface tension in a liquid; but if we were ignorant of the existence of the surface tension, there would be nothing to distinguish this from a case of central "attraction." Moreover, if all of the positive electrification is concentrated in a single electric mass, it would follow that the heaviest atoms must have the smallest central nuclei (because intensity of electrifica-

tion increases as the radius diminishes), which seems a bit paradoxical, since it is natural to suppose that increased mass comes from the addition of new accessions, and this could happen if we suppose that the minute positive electrons are symmetrically arranged in the form of a thin shell. It is also in accordance with all of the electrical analogies that the static part of the electrification should seek the surface. The rapidly moving electrons are elements of electric current, but this does not prevent them from also playing the part of static charge in potency, even though this charge may be neutralized.

### *General Scheme of Electronic Motions within the Nucleus.*

In considering the motions of the negative electrons, some modifications are needed. The Larmor-Bohr-Rutherford atom is likened to a solar system in which the negative electrons, like the planets, move substantially in a single plane. This may be true of certain satellite electrons concerned in chemical action, but I would suggest that not all of the orbital planes need coincide. The larger part of them may be parallel, but distributed on the spherical surface of the atom. The resultant effect will be the same in many respects as if all were in one plane. This leads to a consistent scheme of motions according to the following plan:

Assume as a preliminary conception that all of the electrons in a meridional section of the atom are either ring-shaped, or else approximately oblate spheroidal particles of a uniform size (equatorially expanded by centrifugal pressure of the spin) and with a common (let us say, clockwise) rotation over a given half-section as seen from our point of view; and that they are revolving rapidly in planes parallel to the equator of the atom (with the electrons juxtaposed, pole to pole, or forming virtual vortex-filaments) in definite, but not necessarily invariable orbits, since they may pass into spirals whose *radii vectores* alternately expand and contract when the elastic surface of the atom is disturbed by a collision. The electrons having like rotation mutually repel one another, except in the direction of the spiral vortex-filament; and this may compel some motion of the orbital planes and change of configuration of the orbits during radiation. Juxtaposed electrons on either side of an

equatorial plane are mutually repelled polewards, and this would split the atom into two halves were there not a restraining force.

The electrons are supposed to be rotating at enormous speeds and all in a given set in the same direction of spin in respect to the orbital motion, which will necessarily give the appearance of opposite rotations in the two halves of the same meridional section of the atom. We must presume that these motions are so nicely balanced and take place in a medium so free from viscosity that they form a perpetually regenerating system.

Particles of the sort described are supposed to attract outside particles in proportion to the energy of the electronic motion, and this will vary in direct proportion to the number of electrons included in the atom. The attraction will apparently be that of *pulsatory* motion, or will form waves of longitudinal vibration in the universal aura, passing outward into forms which at first approximate to perfect spheres. Owing to the perfect sphericity of the atomic surface, the combined vibrations of its electrons will generate a composite spherical wave in any case. The orbital motions give rise to vortices in the magnetic medium which are the cause of inertia, and the pulsatory motions produce the changes of density which are the origin of gravity. The conception, it seems to me, affords a rational basis for the conclusion reached by Fessenden on general physical principles, but without attempting to devise details of mechanism, namely, that "the inertia of matter is due to the electromagnetic inductance of the corpuscular charges, and gravitation is due to the change of density of the ether surrounding the corpuscles, this change of density being a secondary effect arising from the electrostatic stresses of the corpuscular charges."[1]

### *The Nature of Positive Electricity.*

As to the nature of positive electricity which is always associated with the negative electrons in the atom, we know nothing, save that it has opposite properties to negative electricity, so that if the shell of positive electricity is composed of discrete *positive* electrons, arranged in circular strands which revolve in the same general direction as the negative electrons and nearly

[1] Science, N. S., vol. 12, p. 327, August 31, 1900.

parallel with them (though the discrete positive electrons may be *rotating* in the opposite sense to the subjacent negative ones), the magnetic field of the positive electrons will have the opposite sign to that of the negative electrons. The positive strands will repel each other, and the positive shell will be strained almost to the bursting point, being retained in position solely by the attraction of the enclosed sphere of negatives. In this view, the sun-and-planets analogy does not hold in the atom, at least not as to the gravitational properties of the nucleus, but *the positive and negative masses are presumably of a like order of magnitude or even identical save in aspect;* and they are complementary in the sense that one requires the other, whereas we can conceive of a sun without planets. If the two spheres are not exactly concentric or not perfectly equal, they form the equivalent of a doublet,[2] and the total electric value of the combination is that of a minute residual, or *difference,* while the gravitational effect is that of the sum of the gravitational forces which do not interfere.

If the combined revolutions and potencies of positive and negative electrons are exactly adjusted, there will result a magnetically neutral atom; but if there is a difference in the positive and negative revolutionary fields within the atom, it becomes a magnet.

### *The Question of Orbital Spirality.*

Professor G. Johnstone Stoney has been the only one I know who has attempted to apply the doctrine of spiral orbits of electrons to explain harmonic series in spectral lines, finding in the case of the A and B groups of the atmospheric spectrum (first described in detail by Langley in 1878 in the Proceedings of the American Academy of Arts and Sciences) that he could account for the remarkable structure of these groups by compounding oppositely rotating spirals of diminishing amplitude which were supposed to give respectively the red and violet components of the pairs of a train. The resultant

[2] Cohesion between atoms or molecules does not arise from gravitational attraction, but follows a law of proportionality to the inverse fourth power of the distance, or after the analogy of the gravitational model, is equal to $Am_1m_2/r^4$. Both Fessenden and Sutherland have shown that this follows as a consequence if we assume the particles to be of the nature of electric doublets. See especially W. Sutherland on The Electric Origin of Molecular Attraction, *Phil. Mag.*, Ser. 6, vol. 17, p. 657-670, May, 1909.

is an exceedingly elongated ellipse, subject to these perturbations: (1) Decrease of amplitude; (2) diminution of periodic time; (3) slow apsidal motion opposite to the orbital revolution of the electron; (4) a slight fluttering motion like nutation; (5) a further slight secular change in the form of the ellipse. As to whether the spiral is the primary motion and the elliptic relations a concomitant resultant of perturbations, or *vice versa*, may not be easy to determine from the mathematics. The supposition as thus stated by Stoney is somewhat vague, and in spite of appearances of spiral relations in the wave-lengths of a series of lines forming a group, or band in the spectrum, it is not easy to see how such definite wave-lengths can result from a perpetually and *gradually* modified series of spiral circulations. Besides this, the oxygen series relates to atoms in molecular combination, and not to dissociated atoms which give quite a different and much simpler spectrum.

A more reasonable supposition is that of Bohr, of which a slight modification is described by Millikan in *Science*,[3] where it is shown that certain orbits whose radii are in the ratio of the squares of the ordinal numbers are stable, but all intermediate orbits are unstable. When, therefore, the position of an electron is disturbed, it passes explosively to the next stable orbit and may repeat the process several times in succession, each transfer giving rise to an electromagnetic vibration in the period of the new orbit. The number of transfers depends upon the thermal energy available. Under the moderate thermal conditions of our laboratories, often only five members of the Balmer hydrogen series are produced and at most twelve; but in the hottest stars over thirty appear.

In any case, the fact of internal orbital revolution of certain electrons in an atom, presumably the satellite or characteristic electrons, is demonstrated by the Zeeman effect, and by the wonderful agreement in the quantitative values which Millikan has deduced from Moseley's measurements (*op. cit.*). The radiation equation $\frac{1}{2}(mv^2) = h\nu$, where $m$ is the mass of an electron, $v$ its orbital velocity, $h =$ Planck's radiation energy factor, and $\nu =$ the vibrational frequency, represents the energy expended in reversing the electric sign, that is, in over-

[3] Radiation and Atomic Structure,—Science, N. S., vol. 45, p. 321, April 6, 1917.

turning the axial pose of a particular electron which, although the direction of motion is not changed, is as if the orbital velocity had been reversed. Except for these instantaneous reversals in the generation of light-quanta, the electronic revolutions never cease, for the atom is a form of extraordinary or almost perpetual endurance, and of relatively enormous energy. The agreement of Rydberg's frequency constant N with the value derived from an application of Kepler's laws to the electronic orbits constitutes, as Millikan remarks, "most extraordinary justification of the theory of non-radiating electronic orbits," and verifies at least this much of Bohr's theory.

*The External Gravitational Potential.*

It is now evident that every atom consists of two parts: (1) the very circumscribed space in which the above mentioned electronic movements are carried on; and (2) the indefinitely extended field of gravitational potential, or strain, in that universal medium which, following Swedenborg, I shall call the magnetic aura, or simply the aura.

The first requisite for any proposed explanation of the facts of gravitation, if it be admitted that a genuine explanation will be of a mechanical nature, is some tentative scheme of a gravitational unit, which shall be capable of generating a longitudinal wave of alternating expansion and compression in the universal magnetic aura. In seeking for such a possible working model, I shall further assume that the aura is divided into complex vortices of galactic dimensions, and that an individual complex vortex constitutes a single independent aural "cell" within which the gravitational motions of its combined masses are confined.

Since all of the motions of the aura are vorticose, this may apply equally to the ultimate direction of propagation of a gravitational wave in the medium. This point may be open to discussion, but is here adopted tentatively on the plea that the electron is probably a polar vortical particle.[4] The wave, therefore, though at first

[4] In another paper ("The Luminiferous Ether," Occasional Scientific Papers of the Westwood Astrophysical Observatory, No. 2, p. 36) I have suggested that the electron itself probably has an internal vorticose motion and polar structure which adapt it to the required function even in its pulsations. But the electronic complex, the atom, is always a perfect sphere.

spherical by close approximation, may ultimately pass into and coincide with a complex of magnetic equipotential surfaces, so that the wave-propagation is not radial, save by close approximation at the start, but follows the direction of the curved lines of magnetic force in the field as finally "magnetically" controlled, and thus returns into itself at the point of initiation. This conception has some analogy with Newcomb's idea that space returns into itself through a fourth dimension; but the latter is highly recondite, and indeed transcendental, whereas my proposition is quite simple and is not disproved by any known facts. Newcomb's conception appeals to me strongly as a feasible means of passing through an intermediate from the world of nature to a world of pure spirit which is not in space of three dimensions; and perhaps the full explanation of gravity will require this further extension of rational thought into the region of genuine causes; but for the present this greater problem and border region of science may be omitted.

If the magnetic analogy be accepted, no energy is wasted in maintaining the mechanism of gravitation. Moreover, the elasticity of the aura is almost infinite, so that the velocity of propagation of the gravitational wave is enormously greater than that of light.[5] According to Professor Fessenden's computation,[6] the velocity of the gravitational wave is $5 \times 10^{36}$ cm. per sec. This is of course simply an inference, but one which rests on reliably known electrical data. Let us suppose that the radius of an aural cell, or the maximum distance to which gravitation is propagated, is 1000 light-years, which will be near enough for a first approximation to the order of the magnitudes involved. The radius of the vortex is then something like $3 \times (10)^{10}$ light-seconds, or $3 \times (10)^{10} \times v = 9 \times (10)^{20}$ cm., if $v$ is the velocity of light; and a complete circulation along a magnetic line of force which extends to this radial distance will be three times

[5] Thomson's (Lord Kelvin's) discussion of a mathematical proposition by Green, in the course of which he arrived at the conclusion that the velocity of gravitation (contrary to the almost universal opinion of astronomers) can not be large, may be placed alongside of his opinion that "it is absolutely impossible to conceive of the currents which he [Ampère] describes round the molecules of matter, as having a physical existence" (Papers on Electrostatics and Magnetism, p. 469). The currents of electronic revolution around the atoms are now thoroughly established, in spite of Lord Kelvin.

[6] R. A. Fessenden, A Determination of the Nature and Velocity of Gravitation, Science, N. S., vol. 12, p. 744, November 16, 1900.

as far, or $2{\cdot}7 \times (10)^{21}$ cm. Even then, for gravitational wave-impulses which travel along this curve and succeed each other at such a rate that a new one does not start until its predecessor has returned, there will be something like two thousand million million waves per second, or a gravitational frequency equal to the radiant frequency in the ultra-violet at $\lambda = 0{\cdot}15\ \mu$. Such impulses, therefore, would not be incompatible with the rapidity of known electronic revolutions, assuming that both have the same periodicity.

### *The Bearing of the Spiral Galactic Form upon the Gravitational Problem.*

William Sutherland, in an article on "Bode's Law and Spiral Structure in Nebulae,"[7] concludes that the spirals in Messier 51 *Canum Venaticorum,* M 100 *Comæ,* and M 101 *Ursæ Majoris,* are "approximately logarithmic." The same view is taken by Pahlen,[8] but has been contested by Dr. T. J. J. See in his Researches on the Evolution of the Stellar System (Vol. II) where he says that

"Thus the similarity of figure always breaks down at some point sufficiently clear and well defined to leave no doubt that the spiral can not be considered, within admissible limits of uncertainty, to be truly equiangular in any one case, and still less is this true of all the different cases where the angles vary so greatly. Consequently the law of attraction operating in the observed spirals can not agree with that of the inverse cube of the distance, under which alone a particle may describe the Logarithmic Spiral" (p. 55).

And on page 59, after noting that "of all the laws of force which give a zero force at an infinite distance, the Newtonian is the only one for which all the orbits are closed curves," Professor See nevertheless ends with the following statement, which seems to me wholly inadequate and misleading:

"The spiral paths shown in the nebulae, however, are neither closed curves, nor any kind of algebraic curves; because the spirals are often broken, so as to become more or less discontinuous, and markedly irregular. Yet it is not to be inferred from this circumstance that

[7] Astrophysical Journal, vol. 34, pp. 251-260, Oct. 1911.
[8] Astronomische Nachrichten, Nr. 4503.

central forces different from gravity are at work among the nebulae. On the contrary, since gravitation is found by observation to govern the motions of the stars, and the nebulae pass by insensible gradations into stellar systems, as is conclusively shown in this volume, it necessarily follows that the central forces operating in the nebulae can be nothing else than universal gravitation; which is a last and sufficient proof that the observed figures of the nebulae are chance spirals, and therefore depart from any kind of geometrical regularity."

If it had simply been said that it is not to be supposed that gravitation is *not* at work in the nebulae, because it is obviously at work in their stellar components, no objection could have been made to such a statement; but when the universally present and peculiar nebular features are ignored and attributed to "chance," and no real attempt is made to explain them, there is urgent need of a different treatment of the data.

It seems to me that Sutherland has supplied the essentials of a correct version. The indications are overwhelming that, while gravitation may not be absent, a different force is in control in these large-scale operations. This force acts according to the inverse *cube* of the distance and is probably magnetic. The law of the logarithmic spiral covers the case well enough. It is not necessary to pin one's faith to some one definite system of logarithms. Sutherland's method picks out that variety of logarithmic spiral which most nearly fits a given case. There are minor deviations which, like the irregularities in comet's tails, point to secondary causes, some of which may be of considerable magnitude; but these do not disprove the continued action of the major force. Thus, for the comet's tail, this force is the pressure of sunlight; and for the spiral nebula it is the magnetic currents of the aura, both of them forces which at first sight seem impalpable, but forces whose power comes from the enormous spaces through which they act.

If it be asked how the currents of the aura can control the motions of the stellar systems, I would answer that the gravitational field is *in* the aura and that, while the energy which is matter is concentrated in material particles, this energy has its complementary reaction which is diffused through an entire sphere of aura. It is, in fact, the interaction of these interpenetrating gravita-

tional fields, each of which extends, if not to the ultimate limits of the aura, still at least within a sphere of aura appertaining to a particular galaxy, which draws the particles together. There is no way of telling whether the gravitational force of a particular galaxy extends to infinity, or only to the boundary of its own sphere of interacting aura, except that which may be inferred from the geometrical structure; but the latter hypothesis, namely, that the sphere of interaction is limited, seems to me the more reasonable one, and we may even suppose that, while there is universal attraction within each aural sphere, the separate spheres mutually repel each other, just as similarly electrified bodies do. In this case the galaxies will be somewhat equably spaced without danger of clashing. The galactic planes, however, lie in every direction without any special preference, or they are apparently wholly independent.

### *A Crucial Test.*

Dr. See assumes that the motion within a spiral nebula is along casual somewhat spiral paths *towards* the center under the attraction of universal gravitation. A. Van Maanen, on the contrary, finds in his research described in the Astrophysical Journal for November, 1916,[9] "Preliminary Evidence of Internal Motion in the Spiral Nebula Messier 101," that the motion is *outward.*[10] He also finds evidence of rotation; but whereas, under the gravitational attraction of a massive central nucleus, orbital motions at radial distances of 2·′2 and 8·′9 should be in the ratio of the inverse squares of the distances, or as 16 to 1, Van Maanen obtains:

At mean distance 2·′2, rotational component = 0·″024,
At mean distance 8·′9, rotational component = 0·″019,

or very nearly the same curved-line speed at both points, and along the paths of the spirals; that is to say, the nebula rotates not as if it were in one piece, but as if there were also uniform stream-motion along the radius away from the center; whence I infer that the motion which we see is not that of matter under gravitational

[9] Vol. 44, pp. 210-228.

[10] For other facts which indicate that development of stellar systems is expansive, rather than concentrative, reference may be made to the author's paper: A Cosmic Cycle, this Journal, vol. 13, pp. 47-58, 97-114, 185-196.

attraction, but is controlled by the motion of a vortex in the aura within which the stellar groups are carried along like dust motes in an air whirl. If the motion had been uniform along *circular* paths around a common center, we might attribute them to a discoidal aggregate revolving under the influence of the mutual gravitational attraction of the parts; but this does not seem to be the case. Since it is obvious that the outward motion can not continue indefinitely without dissipation of the group, and since there is some evidence of deviation from any single logarithmically spiral mode, the velocity is probably not strictly uniform, and the shape probably changes eventually, either by the formation of side branches and diversion into feathery plumes, or by expansion into an annulus. The plume-like extensions may be seen in Keeler's photographs of H I 200 *Leonis,* M 74 *Piscium,* M 101 *Ursae Majoris,* H I 56-57 *Leonis,* H II 730 *Ursae Majoris,* M 88 *Comae Berenices,* M 94 *Canum Venaticorum,* M 63 *Canum Venaticorum,* M 51 *Canum Venaticorum.*[11]

The globular clusters are probably under gravitational control, and a slight vorticity, indicated by a few obvious lines of stars arranged in spiral order, with a very small ellipticity, or tendency to a discoidal shape,[12] are the only evidences of even a remnant of activity of aural currents. Here the currents certainly seem to be subordinate,[13] but in the white nebulae they have control.

If Van Maanen's determination of a radial expansion of 0·″007 per year in Messier 101 is genuine, only 42,000 years would be needed to expand to a radius of 5·′. Such rapid motion would imply a small and relatively near object. A difficulty immediately appears, for Van Maanen makes the period of rotation 85,000 years, and if this corresponds to a real rotational velocity of 260 km./sec. (*op. cit.*, p. 224), such a motion, if due to gravity, would mean that the radius of 5′ is equal to 750,000 astronomical units, parallax = 0·″0004, mass = 57,812,500 × sun's mass. The rotation, if due to gravity, would

[11] Publications of the Lick Observatory, vol. 8, plates 18, 4, 49, 20, 30, 37, 44, 46, 47.

[12] See Francis G. Pease and Harlow Shapley, On the Distribution of Stars in Twelve Globular Clusters, Astrophysical Journal, vol. 45, p. 225, May, 1917. So slight is the ellipticity in M 13 that it was best brought out by arranging the stars on a basis of color-index or variability (p. 229).

[13] The velocities also of the globular clusters, as determined by Slipher, are smaller than those of the spiral nebulae.

require a much greater stellar condensation than that of our Galaxy. The supposition of an aural vortex would remove the difficulty and would permit us to place the nebula at a much greater distance, giving it linear dimensions more nearly comparable with those of our own Galaxy. The extraordinarily rapid expansion must represent a temporary stage of vigorous development, to be succeeded by slower expansion to a final permanent form and quiescence.

*Conclusion.*

The conclusion reached is that the gravitational vibrations are probably confined within definite volumes of a universal medium, or magnetic aura, and are limited outwardly by the form, motion and peculiar properties of this medium which exercises a general control on all gravitative phenomena; so that the larger galaxies resemble discrete organisms, or perhaps a better comparison would be that of discrete and independent, but intimately related cells of one great organism; while the inner limit and origin of the gravitational vibration appears to reside in the pulsating surface of the electronic vortex-ring, or least gravitative unit.

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## Art. VI.—*Some Problems of the Adirondack Precambrian;* by Harold L. Alling.*

Contents.



### *Introduction.*

For our extensive knowledge of the geology of the Adirondack Mountains we owe a debt to Kemp, Cushing, Smyth and Newland, as well as to the later workers in the field; but to these pioneers the credit is due for having laid the foundations upon which W. J. Miller, Ogilvie, Martin and others could build. While it is believed that the major problems are, to some extent at least, solved, there are many problems that have hardly been examined. It is because the writer's experience during the last five years in the area has convinced him that certain phases of the Precambrian have not received a great deal of attention, and because a number of conclusions were reached during a detailed investigation of the graphite deposits[1] that were out of place in a bulletin of an economic character, that this paper is presented.

### 1. *The Grenville Series.*

#### Structure.

The oldest formation in the region, as far as is known, is the Grenville series of ancient sediments,

* Published with the permission of the Director of the New York State Museum.

The writer is indebted to Professors George H. Chadwick and James F. Kemp for reading the manuscript.

[1] The Adirondack Graphite Deposits, N. Y. State Mus., Bull. 199, 1918.

highly metamorphosed into crystalline limestones, quartzites, paraschists and paragneisses. The thickness, the stratigraphy, and. the conditions under which it was deposited are unknown. From the earliest reconnaissance the series has been regarded as highly folded into anticlines and synclines, which subsequently have been severely compressed and squeezed. Recently, however, Dr. W. J. Miller has questioned this belief.[2] He says: "That the Adirondack Grenville strata are more or less folded is admitted, . . . but, in the light of recent studies, the writer (Miller) doubts the interpretation of folded, tilted, and foliated structures as due to intense lateral compression." He recognized that steep dips are universal over the area, but that the Grenville was extensively folded he denied. In view of the fact that the commercial graphite schists are members of the Grenville series it was an economic necessity to arrive at the truth regarding the structure of the old sediments. The writer went into the field with as unbiased a mind as possible but has been convinced by numerous instances of folded strata that Miller's contention is untenable.

The graphite schist that outcrops on Bear Pond Mountain, in the township of Ticonderoga, Essex Co. (Paradox Lake quadrangle), was found to have been strongly folded. The summit of the mountain is probably an anticline while the south side is a syncline, both of which pitch strongly westward. The present surface so truncates the folds that the line of outcrop follows a Z-shaped pattern on the map. On the eastern edge of Hooper Brothers' property, in the township of Dresden, Washington Co. (Whitehall sheet), the succession of the Grenville beds was found to be the reverse of that at the mine. The most plausible explanation is that the rocks have been folded back upon themselves. The rocks all show crinkling and stretching, which is to be expected in such disturbed strata. Another example of anticlinal folding was observed upon the Flake Graphite Company's property, Greenfield, Saratoga Co. (Saratoga quadrangle). Again one and one quarter miles west of Conklingville (Luzerne sheet) the Grenville rocks are dipping 30 degrees north 20 degrees east into a hill. Tracing the beds with care they were found to return sharply on themselves and it was demonstrated that they form a syn-

[2] Miller, W. J.: Jour. Geol., 24, pp. 587-619, 1916.

cline, tightly squeezed, and strongly pitching to the northwest. Four miles south of Clintonville, Chesterfield,

FIG. 1.

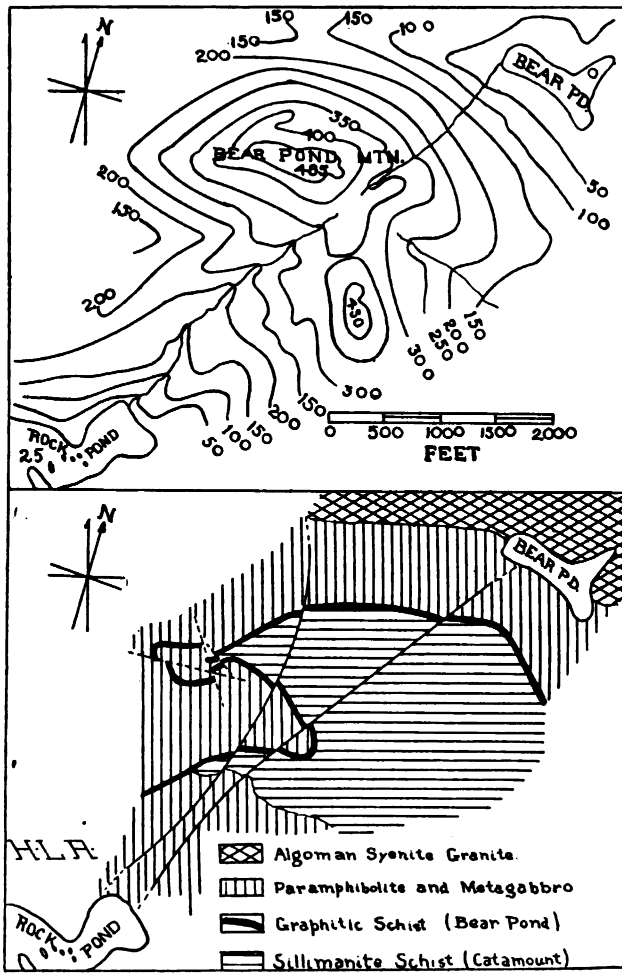


FIG. 1. Geologic and topographic map of the Bear Pond Region, Paradox Lake Quadrangle, Datum plane, Bear Pond. Plane table survey by G. H. Chadwick and H. L. Alling, 1917. Topography by G. H. Chadwick; geology by H. L. Alling. Contour interval 50 feet. The geology is somewhat generalized. Note the isoclinal folding of the graphitic schist.

Essex Co. (Ausable sheet), the graphite schist, together with the associated limestones and quartzites, occur

folded into an anticline which pitches northward. The present surface truncates the fold so that the rocks outcrop in the form of a U. These illustrations show that the Grenville has been folded in the eastern and southeastern Adirondacks. The work of Martin[3] in the Canton sheet and Newland's description of the Edwards zinc-pyrite district,[4] show that the old sediments have been folded in the western area as well.

That the Grenville was folded and highly foliated before the intrusion of the Algoman rocks has been pointed out

FIG. 2.

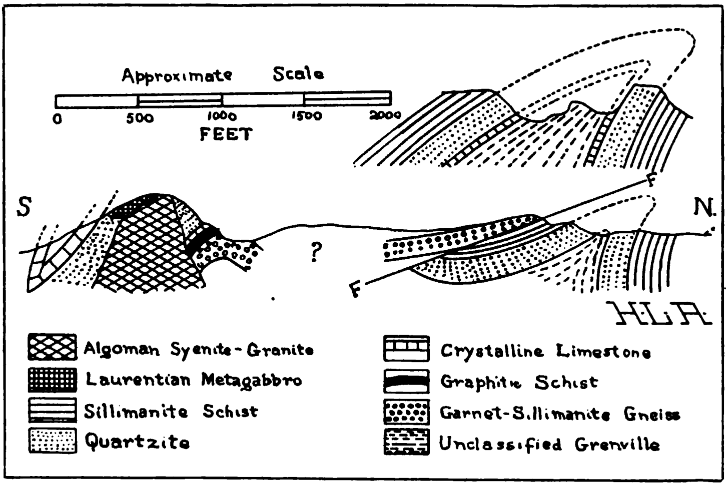


FIG. 2. Geologic reconnaissance north and south sections of the Flake Graphite Co.'s property, Saratoga Quadrangle. Based upon traverse by G. H. Chadwick and H. L. Alling, 1917. Note the overthrust faulting and the isoclinal folding.

by Kemp. He says:[5] "Recent field observations . . . in the vicinity of Keene Valley have shown in massive anorthosite many inclusions of strongly foliated [Grenville para-] gneiss. The foliation of the fragments runs in all directions, even in an area of a few yards. The inference will be drawn that the Grenville [para-] gneisses were already strongly metamorphosed when the anorthosite entered, and that they are very much older than the intrusives." The significance of this observation does

[3] Martin, J. C.: N. Y. State Mus., Bull. 185, pp. 93-108, 1916.
[4] Newland, D. H.: N. Y. State Defense Council, Bull. 2, fig. 3, p. 43, 1917.
[5] Kemp, James F.: Bull. Geol. Soc. Amer., vol. 25, p. 47, 1914.

not seem to have been appreciated. A similar occurrence seen by the writer in the St. Regis quadrangle just south of Mountain pond emphasizes this point. Here xenoliths of anorthosite and foliated Grenville lie embedded in quartz syenite. The hypothesis that the foliation of the Grenville was entirely due to the irregular upwelling of the Algoman intrusives seems to be no longer applicable to the region.

### Grenville Stratigraphy.

It is the hope of Adirondack geologists that the Grenville series can be "put in order." This would seem a hopeless task in view of the lack of organic remains, the extreme metamorphism which they have experienced, and their patchy distribution. Recourse to lithological characters and petrographic similarities is fraught with considerable danger, but the graphite schists themselves furnished more or less reliable datum planes upon which the working out of the stratigraphy could be based. I. H. Ogilvie[6] has already attempted to distinguish the larger units of the stratigraphy. W. J. Miller[7] has listed a large variety of paraschists and paragneisses, but their units were far too large to be used in connection with the graphite deposits. As the beds recognized increased in number, it became necessary to apply names to each formation to act as "handles." This proved to be a difficult task, however, due to the scarcity of geographical names in the sparsely settled Adirondacks and due to lack of time. The following names are purely tentative; and are offered merely as suggestions for further work. Table I is the result of accumulative evidence secured from visiting the graphite properties in the southeastern Adirondacks. Table II is the stratigraphy of the rocks many miles to the north as shown on the George W. Smith property south of Clintonville, Essex County (Ausable sheet) in the northeastern Adirondacks.

### Stratigraphic Details.

The graphite schists are at least two in number. The upper formation, the Bear Pond schist, is an andesine-orthoclase-quartz-biotite-graphite schist. It probably does not extend over such an extensive area as the lower

[6] Ogilvie, I. H.: N. Y. State Mus., Bull. 96, pp. 479-483, 1905.
[7] Miller, W. J.: N. Y. State Mus., Bull. 170, p. 10, 1914.

graphite schist. The "Dixon" have been traced (not continuously to be sure) from the middle of the Ausable sheet south to Saratoga Springs, a distance of 90 miles, and from Hague, on Lake George, west to Conklingville, a distance of 40 miles. It usually exists as a single stra-

| I | | | II | | |
|---|---|---|---|---|---|
| Stratigraphy of the Grenville rocks associated with the graphite schists in the southeastern Adirondacks. | | | Stratigraphy of the Grenville rocks associated with the graphite schists on the George W. Smith property. | | |
| Rock | Name | Estimated Thickness | Rock | Name | Estimated Thickness |
| Paramphibolite | Beech Mountain | 150 ft. | —— | —— | —— |
| Feldspar-quartz graphite schist | Bear Pond | 30 | Feldspar-quartz-graphite schist | Bear Pond | 30 |
| Sillimanite schist | Catamount | 80 | Sillimanite schist | Catamount | 80 |
| Limestone | —— | 20 | —— | —— | —— |
| Quartzite | Swede Pond | 400 | Quartzite | Upper Swede Pond | 350 |
| | | | Limestone | Trout Pond | 50 |
| | | | Quartzite | Lower Swede Pond | 50 |
| Limestone | Faxon | 20 | —— | —— | —— |
| Quartz-graphite schist | "Dixon"[a] | 30 | Quartz-graphite schist | Dixon | 10 |
| Garnet sillimanite gneiss | Hague | 60 | | Absent (?) | |
| | | | Limestone | Chesterfield | 50 |
| Paramphibolite | Dresden | 120 | Paramphibolite | Dresden | 100 |
| Limestone | Johnsburg | 30 | —— | —— | —— |
| Quartzite | Sacandaga | 70 | —— | —— | —— |
| | Total | 1000 | | | 640 |

a This name is preoccupied, see Dixon Formation of Tennessee, Pete, Wm. F. & Bassler, R. S.: U. S. Nat. Mus. Proc., 34, 407–432.

tum, but at the American Graphite Company's mine at Graphite it occurs as two distinct layers separated by bands of the garnet-sillimanite gneiss (the Hague gneiss), but it appears as a single formation four miles to the east at Hague. In the Flake Graphite Company's mine a parting composed of thin beds of limestone and

green quartzite separates the 20 feet seam into two more or less distinct strata. A similar state of affairs was observed on the George W. Smith property.

Probably the most erratic member of the series is the Faxon limestone. At its typical locality along the shore of Faxon Pond, near Graphite, Warren Co., it lies above the "Dixon," but it is absent at Hague as well as at the mines in the South Bay district, along the shore of Lake Champlain. At Hague there is an increased feldspathic content in the lower beds of the Swede Pond quartzite. It is possible that this feldspar schist (which could by analogy to "quartzite" be called an "arkosite") is the stratigraphic equivalent of the Faxon limestone. The presence of the Faxon seems to be confined to the interior of the area. Farther west, 3½ miles west-northwest of Pottersville on the southern edge of the Schroon Lake sheet (International Graphite Company's mine) the Faxon is represented by two beds of paramphibolite, separated by a stratum of limestone. The group taken *en masse* is considerably thicker than the same formation exposed farther east. Here the Faxon appears to be replacing the Swede Pond quartzite by progressive overlap. One interpretation of these observations is that the old shore of the Grenville sea was to the east; that the limestone was deposited in relatively deep water, while the arkosic sands accumulated under near-shore conditions. "Kemp has already emphasized the greater abundance of quartzose [para-] gneisses on the east."[8] Besides this variation in thickness and occurrence of the Faxon it seems to depart from its normal position in some localities and occur within the graphite schist and even beneath it as well. The Chesterfield limestone of the Smith property thus may be equivalent to the Faxon.

The Hague gneiss, typically shown at Hague and at Graphite, is a very interesting rock as already pointed out by Kemp.[9] Besides quartz, feldspar and garnet it contains long slender needles of sillimanite. In its characteristic development it forms the footwall of the "Dixon" schist at most of the graphite properties. At the Rowland Graphite Company's abandoned mine, Johnsburg, Warren Co. (North Creek quadrangle), it

[8] Cushing, H. P.: N. Y. State Mus., Bull. 95, p. 298, 1904.

[9] Kemp, J. F.: U. S. Geol. Surv., Bull. 225, p. 513, 1903. Kemp and Newland: N. Y. State 51st Ann. Rept. II, p. 539, 1897.

becomes a quartzite; the garnet and feldspar content constituting only a minor portion of the rock. Near Conklingville the Hague is highly micaceous. These facts illustrate the variations in the original composition of the clastic deposit.

One of the most puzzling rocks of the Grenville is the paramphibolite, in that it is frequently a difficult matter to distinguish it from metamorphosed gabbros and diabases. The problem of the para- and orthoamphibolites will be discussed on a later page.

Along the southern shore of Paradox Lake beside the state road a very peculiar rock occurs that was at first sight regarded as a diorite porphyry; a most unexpected rock for the Adirondacks. Investigation eventually showed that it was too soft for an igneous rock and furthermore that it grades into a typical crystalline limestone. Under the microscope it was found to consist of a very fine-grained groundmass of calcite in which were embedded "phenocrysts" ("pseudocrysts") of augite, orthoclase, quartz and calcite. All of these grains have been recrystallized and secondarily enlarged. It is possible that it represents a limestone conglomerate.

### The Thickness of the Grenville.

Although the portion of the Grenville studied in detail consists of but a small portion of the whole, the writer cannot regard the original thickness of these ancient sediments to have been as great as W. J. Miller or Adams would have us believe. The evidence that the former presents is based upon the assumption that the Grenville is not isoclinically folded. In view of the fact that isoclinal folds were found in areas adjacent to those described by Miller, the writer doubts the validity of his conclusion.

### 2. *The Saranac Series.*

It is customary with some writers in discussing the geology of the Adirondacks to pass in ascending order from a description of the Grenville series directly to the anorthosite-syenite-granite-gabbro series as though there were no rocks of intervening age. The writer suggests that there may be at least four rock groups that are to be classified in this interval. In large measure the relative ages, extent and relationships of these rocks are unknown

and constitute one of the most difficult problems of the Adirondacks.

It was Cushing[10] who first pointed out the fact that in Franklin and Clinton Counties para- and orthoschists and gneisses occur that are apparently distinct from the Grenville but earlier than most of the igneous rocks of the region. To this group of doubtful rocks he applied the term "Dannemora formation," from Dannemora mountain in Clinton County, suggesting its equivalency with the "Ottawa" gneiss of Canada. Since a possible confusion might arise with a noted Scandinavian locality the name Saranac formation was later substituted. The detail mapping of the Long Lake quadrangle[11] was done some time after the bulletin on the northern Adirondack Region was published. In the latter work Cushing subdivides the doubtful gneisses into two categories: the "Long Lake gneiss" and the "Grampus gneiss." From Cushing's description of the Long Lake gneiss it is evident that it is the ancient granite, that he later assigned to the Laurentian, with the associated metagabbro chiefly as inclusions. Recent work would thus remove the Long Lake gneiss from the doubtful rocks. In the Grampus gneiss we find a "grand mixture" of puzzles. A black and white rock is described. "These rocks have the mineralogy of gabbros and diorites, but the field appearance is often suggestive of a sedimentary origin. There is often a strong resemblance to the rock . . . which Kemp has described as the 'Whiteface' type of anorthosite." There are red acid gneisses which Cushing thinks form the wall rock of many of the nontitaniferous magnetite deposits. In addition there is "a peculiar granitic rock . . . difficult to describe, though easy to recognize . . . it occurs in a great number of Grenville sections, lying in among the sediments, or cutting them out, both above and below."

While it is possible that some of the individual phases of these rocks so designated may turn out to be some one or other of the well recognized rock units, yet it is conceivable that there are rocks in the Adirondacks that cannot be so classified. In mapping the extension of these doubtful rocks into the Blue Mountain Lake quadrangle Miller[12] regarded them as mixtures of the Gren-

[10] Cushing, H. P.: N. Y. State Mus., Bull. 95, p. 299, p. 303, 1905.
[11] Cushing, H. P.: N. Y. State Mus., Bull. 115, 1907.
[12] Miller, W. J.: N. Y. State Mus., Bull. 192, 1917.

ville and Algoman syenite, a clever but a questionable procedure.

North of the town of Saranac Lake the writer[13] encountered them in sufficient quantity in many outcrops to see that they present a special problem of their own. They are penetrated by granites (microscopically quartz monzonites) that are tentatively regarded as Laurentian. Can it be that the sedimentary portions of the Saranac series are Huronian in age? The paraschists and paragneisses are hornblendic or micaceous rocks that do not seem to grade into limestones or quartzites as is the normal behavior of the Grenville. There are portions of the Saranac series that cannot be separated into sedimentary and igneous types, for much lit-par-lit injecting, soaking, and assimilation has taken place.

The writer made some investigation of the doubtful members with the hope that they could be separated into ortho- and para types. Microscopic analyses were made by a modification of Rosiwal's method and the chemical criteria proposed by Bastin[14] applied. As the attempt was far from satisfactory he attempted to make the separation by measuring the relative radioactivity. Joly[15] has pointed out that as a general rule, to which there are exceptions, igneous rocks are slightly more radioactive than sedimentary rocks. Taking typical specimens of the Grenville and of the Algoman syenite it was found that such was the case. The values obtained from tests made upon these Saranac rocks were inconclusive for they were intermediate between the other figures. Without question the electroscope the writer employed was not sensitive enough to give reliable results, but it is hoped that this line of attack can be pushed farther; what the results will be cannot be foretold.

### 3. *The Igneous Rocks.*

#### The Early Metagabbro.

The inclusions of green amphibolites[16] in the granitic rocks of St. Lawrence County present a most difficult problem. Cushing and Martin regard them as igneous

[13] The Geology of the Lake Clear Region (Portions of the Saranac and St. Regis Quadrangles) N. Y. State Mus., Bull. in press.

[14] Bastin, E. S.: Chemical Composition as a Criterion in Identifying Metamorphosed Sediments, Jour. Geol., 17, 445.

[15] Joly, John: Radioactivity and Geology, N. Y. (Van Nostrand).

[16] Martin, J. C.: N. Y. State Mus., Bull. 185, p. 57, 1916.

in origin. The writer examined some specimens taken just south of Canton. His conclusion is in accord with Martin. There are some geologists who entertain the view that some of the red granite of St. Lawrence County is Laurentian in age. If this is true it would suggest that in the orthoamphibolite inclusions we are dealing with a very old eruptive. In the Long Lake quadrangle Cushing found gabbros whose borders were amphibolitic while the cores were hyperitic in character. In discussing their probable age relations he says that he "never found these amphibolitic gabbros in connection with the great intrusives [Algoman], never except in association with the granitic gneisses [Laurentian], the Grenville rocks possibly excepted. The difference [between the two types of gabbros] may perhaps be accounted for on the supposition that the inclosing granitic gneisses were less effective as a protecting buttress against the stresses producing metamorphism, than were the massive and bulky anorthosites and syenites. And while this may be true and the two gabbros, notwithstanding their differences, be of the same age, it seems a much less likely supposition than that the one gabbro is much older than the other and its more profound metamorphism thus to be accounted for."[17]

This was written before the recognition of the granite gneiss as Laurentian but it is just as clear a statement as one recently made to the writer. "There is certainly much [ortho-] amphibolite in the region which is older than the Laurentian and is the oldest eruptive present, so far as I know."[18]

Of course Cushing's observations pertain in large measure to the northern and northwestern Adirondacks. In the eastern and southeastern areas the presence of the old metagabbro has not been emphasized. The writer encountered metagabbros on the graphite properties. Some metagabbros, especially in the southern districts, Whitehall and Saratoga sheets, were proven by field relations to be of post-Laurentian granite, pre-Algoman age. These are discussed later on. Others, however, apparently more metamorphosed, although not definitely assigned to the older metagabbro, may very well be so classified. The orthoamphibolite extensively

[17] Cushing, H. P.: N. Y. State Mus., Bull. 115, p. 466, 1907.
[18] Cushing, H. P.: personal correspondence, November, 1917.

shown on Bear Pond Mountain in the Paradox Lake quadrangle is an excellent example of this ancient eruptive.

### The Laurentian Granite

The existence of a granite much older than the Algoman series of eruptives seems to the writer to have been sufficiently proven to need but little comment. Its universal habit is to be intricately involved with the Grenville series. This led the early geologists to regard it as a Grenville sediment.[19] Even today this view is held by Miller,[20] but the recognition of pegmatitic phases of the rock threw the first doubt upon its sedimentary character . . . while the chemical analysis settled the question.''[21]

The Laurentian granite apparently has its best development in the northwestern Adirondacks in contrast to the southern and eastern areas. There is evidence that there are two distinct periods of metamorphism. One followed the intrusion of the Laurentian granite and the other the intrusion of the anorthosite-syenite-granite-gabbro series. The intensity of the metamorphism of the earlier period apparently was more severe in the northwest than in the southwest. In contrast to this the disturbance that came later was more pronounced in the southeast. Thus in the north and northwest the Laurentian rocks are folded and foliated together with the Grenville while the later igneous rocks are much less metamorphosed. This makes the distinction between the two groups possible in the northwest while it is a difficult matter to distinguish the two granites in the southeastern area, for both series suffered metamorphism together. This in part accounts for the different views held by Cushing and Miller.

That an old granite does occur in the southeastern Adirondacks the writer feels positive; Cushing's work in the Saratoga sheet was found by the writer to have been exceedingly well done; the Laurentian granite is there. The presence of the old granite was very common on most of the graphite properties. The rock that directly underlies the Hague gneiss (garnet-sillimanite-

[19] Cushing, H. P.: N. Y. State Mus., Bull. 77, pp. 17-19, 1905.
[20] Miller, W. J.: N. Y. State Mus., Bull. 182, p. 11, 1916.
[21] Cushing, H. P.: N. Y. State Mus., Bull. 169, p. 21, 1914.

gneiss) on the Dixon-Faxon properties and at Hague is a syntectic, due to the "soaking" of the bottom layers of the old sediment by the Laurentian granite. But at moderate depths a fairly clean fine-grained granite (or perhaps a better term would be quartz monzonite), is found. This ancient eruptive is present on the Hooper property, not beneath the foot-wall, but as lit-par-lit injecting and saturating the Swede Pond quartzite. Its behavior in affecting one stratigraphic unit here and a different one there and its entire absence in a third locality, is very suggestive of the igneous nature of the rock. What seems conclusive evidence, to the writer, was obtained at the Sacandaga Graphite Company's mine near Conklingville (Luzerne sheet) in an exposure showing the later granite cutting the Laurentian. The latter is a quartz monzonite, slightly garnetiferous, grading into a monzonite which locally has been granulated into a "pulpy" rock that has a remarkable resemblance to the crushed anorthosite of the central Adirondacks. The writer is thus in full accord with Professor Cushing in his conception of the constitution of the Adirondacks; believing that it consists of the Grenville lying upon ortho-gneiss (Laurentian) which later was invaded by the anorthosite-syenite-granite-gabbro eruptives.

The writer has observed the Laurentian soaking the Grenville in many localities but this effect seems to be limited to the siliceous members of the old sediments; the Hague, the Swede Pond and the Sacandaga formations being peculiarly subject to its influence, while the more femic rocks such as the Beech Mountain and the Dresden paramphibolites apparently escaped attack. It is difficult to understand why this should be so, and this presents a special problem for the future.

One of the reasons why the Laurentian quartz monzonite has been recognized only of late is that it has been folded together with the Grenville and furthermore that its eruptive behavior is laccolithic rather than batholithic. This characteristic is in an economic sense an important fact not at first appreciated. The "Dixon" schist dips southward on the Flake Graphite Company's land (Saratoga sheet) into a hill. The summit of this elevation is composed of granite. In the field it was not readily decided which granite it was. Petrographically it proved to be a quartz-microperthite-syenite, inter-

preted as belonging to the later group of plutonics. This has an important bearing upon the amount of graphite ore that could be expected in depth. If it proved to be the Laurentian a greater continuation of the "Dixon" schist could reasonably be expected.

### The later Metagabbro.

An early metagabbro has already been mentioned as occurring in the Adirondacks; a *pre*-Laurentian-granite eruptive. The writer feels confident that he has sufficient proof to substantiate the claim that there is also a *post*-Laurentian-granite metagabbro in this region. In the southeastern Adirondacks W. J. Miller[22] has called attention to the boss and pipe-like behavior of the later gabbro. The behavior of this older rock is decidedly different both in its form and mineral make-up. It is often laccolithic in character. The chief ferromagnesian mineral is hornblende which frequently becomes so dominant that the rock should deserve the term hornblende orthoschist. The writer has evidence, he believes, that it is later than the Laurentian granite, in an occurrence on the Flake Graphite Company's land where the metagabbro is cutting the Laurentian granite-injected Swede Pond quartzite; furthermore, the metagabbro is in turn cut by the later granite.

The finest example of this metagabbro known to the writer is on the Hooper property, west of Whitehall, where remnants of an extensive laccolith form a capping rock to the Grenville sediments. In contact with the Swede Pond quartzite the rock exhibits marked chill effects which resemble in a remarkable way the normal diabase of the region. It has lit-par-lit injected the surface of the already soaked Swede Pond formation. At one spot on the property a boss of the later granite cuts the syntectic Swede Pond gneiss (the quartzite saturated by magmatic solutions of the Laurentian), giving within a limited area the age relations of the important rock units of the Adirondacks.

While there is no doubt in the writer's mind that this metagabbro, as is shown here, is of igneous origin, the distinction between many paramphibolites and orthoamphibolites is an exceedingly difficult matter. The writer encountered several occurrences where it was

[22] Miller, W. J.: N. Y. State Mus., Bull. 170, pp. 26-27, 1914.

impossible to so classify the rock. In some doubtful cases the rocks were studied petrographically. Specimens were collected from rock masses where field relations pointed to a definite origin. Microscopic examination revealed striking similarities and a few differences. The similarities need not be touched upon; it is the latter that are important. If the rock is sedimentary in origin and derived from a calcareous shale as Cushing suggests,[23] quartz would be expected to occur, as unmetamorphosed shales almost universally carry some quartz. Thus if any original quartz is present in an amphibolite it gives it a sedimentary look, for basic (subsalic, femic) rocks are usually lacking in this mineral. On the other hand the absence of quartz suggests an igneous origin, but this may not be a safe criterion, in that quartz may have been reorganized into meta- and trisilicates.

Seeking for a more reliable distinction the pyroxene-amphibole (the pyribole of Johannsen[24]) content was examined. It is held by many geochemists[25] that pyroxene is a high temperature mineral, while amphibole is a lower temperature form. The change from one to the other being a paramorphic (or "autometamorphic") one—a change readily brought about by the stresses of dynamic and static metamorphism,—the inversion of pyroxene to amphibole furnishes some aid in the problem in hand. If a large amount of pyroxene, such as augite, is found in an amphibolite it suggests an igneous origin. But under the stress of severe metamorphism this inversion may be complete. Martin[26] found this to be true of the amphibolite inclusions in the granitic rocks in the Canton sheet (St. Lawrence Co.). Thus the absence of augite does not necessarily prove a sedimentary parentage, but merely suggests it. This criterion, like the former, is therefore regarded as inconclusive.

Hunting for additional criteria, the writer investigated the feldspars in turn. It was found that the igneous types usually contained a simple range of feldspars, such

[23] Cushing, H. P.: N. Y. State Mus., Bull. **169**, p. 19 and Bull. **191**, p. 15, 1914.

[24] Johannsen, Albert: Jour. Geol., **19**, p. 319, 1911.

[25] Elsden, J. V.: Principles of Chemical Geology 1910, p. 114. Becke: Tsch. Min. u. Petr. Mitt., **16**, pp. 327-336. Clarke, F. W.: U. S. Geol. Surv., Bull. **616**, p. 386. Lacroix, Minéralogie de la France, I, 1893-1895, pp. 668-669.

[26] Martin, J. C.: N. Y. State Mus., Bull. **185**, p. 157, 1916.

as 10% orthoclase and 20% andesine, while the sedimentary rocks frequently exhibited a motley collection; covering a much wider range. Very commonly soda-orthoclase, microcline, perthite, oligoclase and labradorite were seen in a single microscopic slide. This was explained with the aid of the equilibrium diagram of the orthoclase-albite-anorthite system proposed by Vogt,[27] Marc,[28] Becke,[29] Harker,[30] supported by the observations of Day,[31] Allen,[31] and Warren.[32] If the feldspar composition, in the magma, was on the potash side of the eutectic line the resulting crystals would be dominantly the orthoclase type of feldspar, while if it was on the other side plagioclase (plus a little potash feldspar) would result. But if the position of the molten feldspar was on or near the eutectic line the solid minerals would be divided on freezing into orthoclase (carrying a little soda feldspar in solid solution) and plagioclase.

The criteria may be summed up as follows:

| *Sedimentary Origin* | *Igneous Origin* |
|---|---|
| Original Quartz | High pyroxene content |
| Motley collection of feldspars | Evenly "split" feldspars |

How successfully these criteria have been applied to amphibolites whose origin was not forthcoming from the field relations cannot as yet be stated, but the hope is entertained that some progress has been made in this difficult problem.

## 4. *The Algoman Series.*

*The Anorthosite.*—The anorthosite-syenite-granite and gabbro series have received a great deal of attention. It was Cushing[33] who first pointed out in the Saranac-Long Lake Region that the anorthosite was the oldest rock of the group, by finding dikes of the syenite cutting the anorthosite. The writer can bring into court two

[27] Vogt, J H. L.: Silikatschemelzlosungen, 1914, II, pp. 120-1.

[28] Becke, F.: Tschermak, Min. Petr. Mitt. (2) 25, 106, pp. 361, 383-85, 1906.

[29] Marc, Robert: Vorlesungen uber die Chemische Gleichewichtslehre und ihre Anwendung auf die Probleme der Mineralogie, Petrographie und Geologie. Fig. 68, pp. 69, 111-112.

[30] Harker, Alfred: Natural History of Igneous Rocks, p. 250, 1911.

[31] Day, A. L., and Allen, E. T.: Carnegie Inst., Publ. 31, 1905.

[32] Warren, C. H.: Am. Acad. Sci., 51, No. 3, pp. 127-154, 1915.

[33] Cushing, H. P.: N. Y. State Geol., 20th Ann. Rept., p. r25-r46, 1900; N. Y. State Mus., Bull. 95, pp. 318-322, 1905. N. Y. State Mus., Bull. **115**, p. 481, 1907.

new occurrences showing the anorthosite cut by dikes of the syenite. In the St. Regis quadrangle, just south of Mountain pond a dike of quartz syenite cuts the anorthosite; the other exposure is in the Saranac Lake sheet two miles west of Gabriels (Paul Smiths Station) beside the state road.

The anorthosite has been the subject of a very valuable paper by Bowen.[34] From the study of the binary system of solid solutions, albite-anorthite, he concluded that the anorthosite, essentially a labradorite rock, was not molten as such, suggesting that the anorthosite is a differential phase of a gabbroic magma. He pictures a huge laccolith invading and splitting the overlying Grenville series, which differentiated into an upper layer of syenite-granite and a bottom one of gabbro and an intermediate zone of anorthosite. The suggestion of a laccolith is a new conception and may furnish the explanation of some of the obscure problems of the Algoman. The writer, however, takes exception to Bowen's view that a genetic relation exists between the syenite and anorthosite. The chill phases of the syenite are frequently monzonitic to dioritic in composition. As the ferromagnesian minerals are commonly pyroxenes the rock as such can be called gabbroic but in no case has it been the writer's experience that a "syenitic" phase of the anorthosite occurs. The writer grants the close kinship between the anorthosite and the gabbro but questions a similar relation between the anorthosite and the syenite, although realizing that they are nearly contemporaneous in age.

Bowen's suggestion that the Algoman rocks are laccolithic rather than batholithic is a valuable one. One of the problems of the Adirondack Precambrian is to account for the non-discovery of the Grenville floor. If the Algoman magma arose, and injected the overlying Grenville as a huge laccolith, it would, perhaps, account for this failure. This suggestion, however, assumes that the syenite has been derived from a single mass. As Cushing points out,[35] it is difficult to account for the present exposures on this basis. To explain the outlying syenite and granite bodies away from the anorthosite the postulation of several other magmas, which may have

[34] Bowen, N. L.: The Problems of the Anorthosite, Jour. Geol., 25, p. 223, 1917.

[35] Cushing, H. P.: Jour. Geol., 25, No. 6, p. 508, 1918.

been only slightly later in age than the anorthosite, seems necessary.

Bowen does not discuss the Whiteface type of anorthosite, a rock studied and named by Kemp. In the Lake Placid sheet the writer has found limestone-contact-zones due to the igneous activity of the Whiteface (and possibly one due to the "Mt. Marcy") type of anorthosite. This shows that mineralizers were not entirely lacking, contrary to Bowen's conclusions. The age relations of the two types, in so far as the writer knows, have not been established. The writer's feeling is, however, that we are dealing with two separate intrusives.

In the Mt. Marcy sheet, on the west slopes of Baxter mountain, large xenoliths of the Mt. Marcy type, highly foliated, are engulfed in a mass of the same type of anorthosite. A similar state of affairs is seen at Split Rock Falls[36] in the Elizabethtown quadrangle, where a peculiar type of rock is developed. How are we going to interpret these observations and reconcile them with Bowen's conclusions?

*The Gabbro.*—Away from the large areas exposing the Algoman gabbro this rock occurs as pipes and stocks. This characteristic behavior is beautifully shown in the North Creek sheet, as W. J. Miller has pointed out. But on the Dixon-Faxon graphite properties at Graphite the Algoman gabbro occurs as true inter- and intra-formational laccoliths—a most unexpected form of an igneous mass. Swede Pond mountain seems to have been formed by the injection and development of a laccolith beneath, doming up the quartzite, so that distinct and opposite dips are observable on the north and south slopes of the hill. One small laccolith on the shore of North Pond is just unroofed by the construction of a state road.

*The Term "Algoman".*—The name Algoman, perhaps, needs a word in the way of explanation. The term "anorthosite-syenite-granite-gabbro series" is obviously a clumsy expression. Miller has employed the term syenite-granite in his writings. To those who have followed the progress made by the Adirondack geologists no confusion arises. But with the recognition of the old granite, which Cushing regards as Laurentian, the need for an analogous name to apply to the later series becomes very desirable. While it would have been more

[36] Kemp, J. F.: N. Y. State Mus., Bull. 138, p. 39, 1910.

conservative to have chosen a more local name than "Algoman," yet Cushing has proposed a term in "Laurentian" which has from time to time possessed different shades of meaning. The writer does not claim that the term Algoman as applied to the later series of eruptives is original with him. He has heard it used in the field, perhaps more commonly by St. Lawrence county geologists. The Precambrian rocks of Canada have been studied in sufficient detail to furnish data for numerous correlation tables, twenty of which have been examined. There is a striking similarity in nearly all; there are only two periods of igneous activity prior to the Keweenawan. The old granite is regarded as Laurentian, hence, if we follow W. G. Miller and Knight[37] we are, perhaps, compelled by the force of circumstances to employ the term Algoman; it furnishes a much desired "handle."

### The Gabbroic Dikes.

The writer has encountered several dikes, usually only 3 to 4 feet wide, that are of peculiar composition. They are strikingly equigranular and composed of labradorite, augite, garnet and magnetite. Sometimes hornblende and biotite occur in addition. Mineralogically they can be classed as gabbros but no diabasic or gabbroic texture is visible even under the microscope. One occurs at Euba Mills, in the Elizabethtown quadrangle, another a mile south of the town of Saranac Lake on the shore of Lake Flower, a third one was seen on the Blue Ridge-Newcomb road in the Schroon Lake sheet. Still another occurs at the eastern entrance of the Gulf, in the Ausable sheet. In each case they are cutting anorthosite. Undoubtedly more will be encountered as field work is continued.

### Diabase and Trachyte.

On the Faxon Graphite property, Bolton quadrangle, Mr. D. H. Newland pointed out to the writer a diabase dike which has assumed a most peculiar form. It is of normal Adirondack diabase, olivine free. Instead of behaving like the rest of the dikes of the region it has failed to reach the surface, expending its energies in the formation of a laccolithic body some 300 feet long and 25 feet thick. It splits the "Dixon" schist into two seams.

[37] Miller, W. G., and Knight, C. W.: Jour. Geol., 23, p. 588, 1915.

This unusual laccolithic diabase is exceptionally well shown by the excavation made for the state road that runs from Chestertown to Hague.

Kemp and Marsters[38] have emphasized the variations in the diabase dikes, especially those occurring in the

Fig. 3.

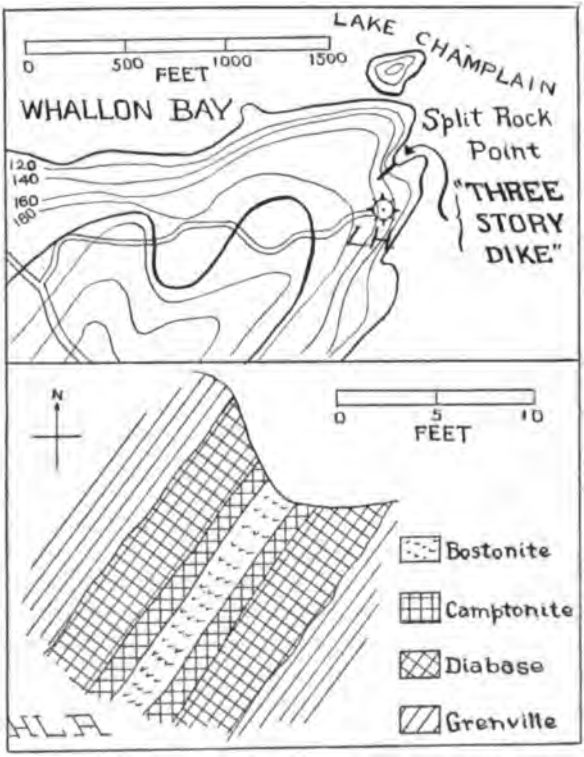


Fig. 3. Sketch map and detail drawing of "Three story dike" on Split Rock point, Lake Champlain, N. Y., H. L. Alling, 1918.

Champlain Valley. Just north of the lighthouse on Split Rock, Willsboro sheet, a group of dikes of unusual interest is located. When Kemp and Marsters visited this locality a boathouse, situated astride them, obscured them from view. This building has subsequently been removed, giving access to them. Apparently a dike of nearly normal diabase, originally 6 or 7 feet wide, perhaps slightly porphyritic and approaching an augite

[38] Kemp, J. F., and Marsters, V. F.: U. S. Geol. Surv., Bull. 107, 1893.

camptonite, fractured longitudinally to allow a second and later dike of hornblende camptonite to intrude. This was about 3 feet wide. This in turn split to allow a third dike to sandwich its way in. This is a typical bostonite dike 2 feet in width. Each dike has developed chill phases upon its neighbor; a narrow contact zone of several inches occurs between the porphyritic diabase and hornblende camptonite. A more ideal exposure to show the age relations of the dike rocks cannot be imagined.

### *The Age of the Faulting in the Adirondacks.*

It has impressed the writer that the faults are not all of the same age. With such complex geology as is shown in the region it would seem remarkable if the faults had been contemporaneous. Positive proof of various ages was secured in the Saratoga sheet on the property of the Graphite Products Corporation, 4 miles north of Saratoga Springs. The graphite schist occurs as two (and possibly as three) outcrops due to repetition by faulting. The fault lines run east and west, which are abruptly cut off by the north and south fault (McGregor fault) that brings the Canajoharie shale in contact with Grenville. Thus there is post-Grenville-pre-Cambrian faulting as well as that occurring since Cambrian times. A mile south of the town of Saranac, one of the unusual gabbroic dikes has re-cemented a fault zone in the anorthosite; engulfing brecciated fragments as xenoliths demonstrating pre-gabbroic dike faulting. When the region is made the subject of a serious physiographic study the relative ages of the faults should be kept in mind.

### *Summary.*

The following points were brought to light or emphasized during a detailed investigation of the Adirondack Graphite Deposits during 1917 and 1918:

1. That the Grenville strata have been extensively isoclinally folded.
2. That the stratigraphic units formerly proposed in attempting to put the Grenville in order are too large, but when smaller units and the graphite schists are taken as a basis, then it is possible to do something with the

old sediments. One thousand feet of the series have been studied in detail and subdivided into 12 formations which can be traced over considerable area.

3. That individual phases of the Saranac Series may be some one or other of the well recognized rock units, yet it is quite possible that other phases cannot be so classified.

4. Recognition of the presence of an ancient metagabbro antedating the Laurentian granite.

5. Recognition of the presence of a granite (quartz monzonite) older than the anorthosite-syenite-granite-gabbro series. This is the Laurentian granite.

6. The establishment of a metagabbro closely following the intrusion of the Laurentian granite.

7. Some amphibolites were found to be of sedimentary origin, that is, members of the Grenville series, while others are metagabbros. Criteria for the recognition of the different types are here presented.

8. The occurrence of the Algoman gabbro and the normal diabase in laccolithic bodies.

9. The presence of some peculiar gabbroic dikes.

10. The post-diabase age of the camptonite and bostonite dikes.

11. That the faults of the Adirondacks are not all of the same age.

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# SCIENTIFIC INTELLIGENCE.

## I. Chemistry and Physics.

1. *The Arrangement of Electrons in Atoms and Molecules.*—Irving Langmuir has presented an important contribution to this interesting subject. He says that the problem of the structure of atoms has been attacked mainly by physicists who have given little consideration to the chemical properties which must ultimately be explained by a theory of atomic structure, and that Kossell and also G. N. Lewis have had marked success in attacking the problem in connection with the properties and relationships indicated by the periodic system. Lewis has reasoned from chemical facts that the electrons in atoms are normally stationary in position, that they arrange themselves in a series of concentric shells, the first shell containing two electrons, while the other shells tend to hold eight. The outermost shell, however, may hold 2, 4, or 6 instead of 8. The eight electrons in a shell are supposed to be placed symmetrically at the corners of a cube or in pairs at the points of a tetrahedron, and when atoms combine they are supposed to hold some of their outer electrons in common, two electrons being thus held for each chemical bond.

Kossell has conceived the electrons as located in a plane in concentric rings, rotating in orbits about a nucleus, and his theory has many points of similarity to that of Lewis. It is pointed out by Langmuir, however, that each of these theories in its present form fails to explain the properties of a large part of the elements, especially those of higher atomic weights.

Langmuir has therefore advanced a theory of his own, extending Lewis's idea of the cubical atom, and making use also of certain ideas of Kossell. His speculative postulates and conclusions are so numerous that no attempt can be made to give a summary of them here, but a few aspects of his theory may be presented. In attempting to determine the arrangement of electrons in atoms he has been guided in the first place by the numbers of electrons which make up the atoms of the inert gases, in other words by the atomic numbers of these elements, namely, helium 2, neon 10, argon 18, krypton 36, xenon 54, and niton 86. Rydberg has pointed out that these numbers are obtained from the series

$$N = 2(1 + 2^2 + 2^2 + 3^2 + 3^2 + 4^2 +)$$

Langmuir draws the conclusion that these numbers represent the electrons in perfect atoms with complete outer shells, and thus decides upon the numbers of electrons in each shell. He believes that the electrons of any given atom are distributed through a series of concentric (nearly) spherical shells, all of equal thickness, while the mean radii of the shells form an arith-

metic series 1, 2, 3, 4, and the effective areas are in the ratios $1:2^2:3^2:4^2$: That each shell is divided into cellular spaces or cells occupying equal areas: That the first shell contains 2 cells, the second 8, the third 18, and the fourth 32: That each of the cells in the first shell can contain only one electron, but each other cell can contain either 1 or 2: That all of the inner cells must have their full quota of electrons before the outside shell can contain any: That no cell in the outside layer can contain two electrons until all the other cells in this layer contain at least one.

It appears that this theory of atomic structure not only explains in a satisfactory manner the general properties and relationships of all the elements, but also gives a theory of the formation and structure of compounds which agrees excellently with the facts.—*Jour. Amer. Chem. Soc.*, **41**, 868.

H. L. W.

2. *Qualitative Chemical Analysis;* by WILFRED WELDAY SCOTT. 12mo, pp. 350. New York, 1918 (D. Van Nostrand Company. Price $2.50 net).—This is the third edition, completely revised and enlarged, of an unusually extensive text book on qualitative analysis. One of the satisfactory modifications of this last edition is the introduction of a large number of chemical equations for the purpose of explaining the reactions. The book is essentially a laboratory guide with extensive directions for the work of students, but it gives much also in the way of explanations, notes and systematic questions for class-room use. There are many tables explaining analytical operations, showing the reaction of metals and acids, the properties of inorganic compounds, etc.

The book is an impressive one from the very large amount of information that it presents, and for the generally excellent manner of presentation. Perhaps the course that is given may be considered too elaborate for many classes of beginners, but it must be admitted that it is easier to omit portions of an extensive text book than to supply deficiencies with one that is too short. There is room in many cases for differences of opinion in regard to the selection of analytical methods, but it may be said that in the book under consideration several methods of detection or separation are frequently described, and that the methods are generally well chosen. H. L. W.

3. *The Origin of Spectra.*—In a recent theoretical paper by J. J. THOMSON an explanation of the origin of spectra is given which leads to results of the right kind and which is very helpful in forming a mental picture of the processes of radiation. Of course, the author does not claim that his point of view is the only correct one, on the contrary he points out the possibility of an infinite number of laws of force each of which would account for the observed facts and not conflict with well established electrodynamical principles.

In the first place, if the law of electric force had the form $r^{-2}(1-c_1r^{-1})\ (1-c_2r^{-1})\ (1-c_3r^{-1})$, where $c_1$, $c_2$, $c_3$ are of the order of atomic distances, and $r$ is the distance from the positive nucleus, there would be no lack of accord with the inverse square law for actual experimental distances, which are always enormous in comparison with atomic magnitudes, $10^{-8}$ cm. On the other hand, the force would change from attraction to repulsion when $r$ assumed any one of the values $c_1$, $c_2$, $c_3$. Since the law of force within the atom is not known there is no objection to assuming the alternation of sign involved in the above expression. Instead of using the preceding multiplier of $r^{-2}$, Thomson prefers the factor $(\sin cu)/cu$, where $u = 1/r$. Inside the atom, if atomic dimensions are comparable with $c$, there will be a series of positions of equilibrium for an electron determined by $cu = n\pi$ where $n$ is an integer. Thus even if there is only one positive charge and one electron (hydrogen) there may be a singly infinite series of atoms with the electron at distances from the center represented by $r = c/n\pi$. The times of vibration of the electrons about these positions would be different, so that a collection of such atoms could give rise to an infinite number of lines both in the absorption and emission spectra. Among other things, this conception accounts qualitatively for the observed decrease in the intensity of spectral lines of a given series as the term number of the line increases.

Further progress is made by supposing that magnetic instead of electric forces are predominant in determining the electronic vibrations. In this case it is convenient to assume that the value of the magnetic induction, at a point of equilibrium at a distance $r$ from the center, is given by $\mu(a^2-r^2)$. This distribution of magnetic force is not *a priori* improbable as it is that inside a sphere uniformly electrified and rotating like a rigid body. It is then shown that the frequencies in these positions would be proportional to $\frac{c^2}{\pi^2}\left(\frac{a^2\pi^2}{c^2}-\frac{1}{n^2}\right)$, which expression represents a series of the Balmer type. If, in addition, the place $r = a$, where the magnetic force vanishes, is also a place where the electric force vanishes, $\frac{c}{a}=m\pi$ where $m$ is an integer, and the expression for the frequency becomes $C\left(\frac{1}{m^2}-\frac{1}{n^2}\right)$, where $C$ is a constant. The type of atom which is required to satisfy the assumptions made in the analysis is described as follows. "This atom consists of a field of electric force which may be regarded as made up of a series of shells of attractive and repulsive force following one another alternately, the radii of the boundary of these shells, which are places where an electron would be in equilibrium, being in harmonical progression. Superposed on the field of electric force is a field of magnetic force, also

arranged in shells, the outer boundary of the magnetic field coinciding with a place where the electric force vanishes.''

When more than one electron forms a part of the normal atom, the position of equilibrium will not be where the force due to the positive nucleus vanishes, but where this force at any electron balances the repulsion due to the other electrons. Therefore the earlier condition $cu = n\pi$ changes to $cu = \pi(n + \delta)$, where $\delta$ is a quantity depending on the repulsion of the electrons and perhaps also on $n$. The frequency formula now assumes the Rydberg form $1/(m + \delta')^2 + 1/(n + \delta)^2$. In the discussion of this expression, Thomson shows that the processes of ionization and a supposed shrinking toward the center of the outer boundary of the magnetic field account for the existence of a principal series, of the first and second subordinate series, and of the well-known mutual connections between these series such as the Rydberg-Schuster law, common convergence frequencies, etc. Doublets and triplets arise from asymmetry, with respect to the nucleus, in the distribution of electrons belonging to the same ring, since this asymmetry would cause $r$ to have slightly different values for the various electrons and hence give rise to different frequencies of vibration.

In addition to the topics barely suggested above, the paper contains a wealth of other valuable material for the details of which the reader may be referred to the original text. Two remaining points, however, deserve special notice. By assuming a certain simple relation between the electric and magnetic forces, Thomson deduces Planck's law. He also calculates the number of waves in a train, after proving that the time taken for the energy lost by radiation to fall to $1/e$ of its initial value is equal to $10^{22}/5n^2$. This leads to $4 \times 10^6$ waves for the D lines of sodium, and to 660 waves for the characteristic X-rays of the L series of platinum.—*Phil. Mag.*, **37**, 419, 1919. H. S. U.

4. *Absorption of X-Rays.*—The relative absorption coefficients of X-rays, for a comparatively large number of different elements, have been very thoroughly investigated by T. E. Aurén. The success of the work was largely due to the application of a compensation method, for which the apparatus was admirably designed, and to the care taken to minimize and correct for small sources of error. The chief results obtained may be summarized as follows:

(1) In the chemical compounds examined the additive law has been found to hold unqualifiedly. With the possible exception of carbon, the state of aggregation seemed to have no influence on the quantity of absorption. The valency of the same element as a constituent of different compounds had no detectable effect on the magnitude of the absorption of the element in question.

(2) The relation between the atomic absorption coefficients of nearly all of the elements from hydrogen to silver (also lead) and the atomic absorption coefficient of copper have been determined at the wave-lengths 0·30, 0·34, 0·36, and 0·38 A.

(3) On the assumption that the absorption of hydrogen is due exclusively to scattering produced by the electron combined with the positive nucleus, it has been found that the scattering for other elements is due, in all probability, solely to the electrons constituting the outer layer of the respective atoms. On the basis of the relative atomic absorption coefficient of hydrogen, the number of "outer electrons" has been estimated for the lighter elements.

(4) The atomic absorption coefficient increases for different elements nearly proportionally to the atomic number. This fact, taken in conjunction with the interpretation of the atomic number as the number of electrons associated with the positive nucleus, makes it possible to determine the distribution of electrons between the inner and outer regions of the atoms.

(5) The number of outer electrons in the lighter elements seems to be constant for the elements placed in the same vertical column of the periodic table. The distribution of electrons thus appears to be closely connected with the periodicity of the chemical properties of the elements as expressed by this system.—*Phil. Mag.*, **37**, 165, 1919.

H. S. U.

5. *Experimentelle Untersuchungen über die Beugung elektromagnetischer Wellen an einem Schirm mit geradlinigem Rande;* by Martin Sjöström. Pp. vi, 110. Uppsala, 1917 (Edv. Berling).—This monograph contains a detailed account of an elaborate experimental investigation of the diffraction of short electric waves at the rectilinear edge of a large plane screen. The theoretical object of the work was to test Maxwell's electromagnetic equations on a special case which is susceptible of rigorous mathematical formulation and which is very exacting, if not crucial, with respect to the original equations. The theory of the diffraction field corresponding to a point source and an infinite screen, the straight edge of which is parallel to the direction of vibration of the linear oscillator, has been worked out exactly on the basis of Maxwell's equations by C. W. Oseen. Accordingly Sjöström designed his apparatus to conform as closely as possible to Oseen's hypotheses. By using short electric waves the experimenter was able to explore the complicated parts of the field very close (down to one quarter of a wave-length) to the edge of the screen, a scientific feat which

is not feasible in the case of ordinary light because of the extremely short wave-lengths of visible radiations.

A few facts about the apparatus merit attention. The linear oscillator consisted in a spark gap 0·46 mm. long. The sparks passed in a stream of hydrogen gas which was saturated with alcohol vapor. The resonator was provided with a detector of new form, the details of which are partially withheld because of certain patent rights. Its success, however, seems to depend primarily upon the use of a crystal of molybdenum-glance. The waves emitted by the oscillator had a length of 40 cms. and a logarithmic decrement of about 0·6. The vibrations of the resonator were strongly damped (1·2). Both the oscillator and the resonator were kept at a distance of five wave-lengths (200 cms.) above the floor. The screen consisted of a zinc sheet 0·4 mm. thick, the other dimensions being 290 and 300 cms. The diffracting edge was vertical so that all explorations were made in the equatorial plane of the vertical oscillator.

After applying small corrections, necessitated by the presence of slight unavoidable disturbing influences, the intensities obtained experimentally agreed with the values calculated from Oseen's analysis, well within the limits of observational error. The monograph closes with a two-page chart of the loci of constant intensity. This map is very instructive since its contour lines bring out the intensity hills and valleys very strikingly, and as it illustrates the parallel case in optics. The investigation brought to light a new phenomenon which is consistent with Oseen's theory so far as the calculations have as yet been carried. It is this, the intensity of the diffraction field as obtained with Hertzian waves fluctuates within the geometrical shadow of the screen instead of falling off gradually and smoothly as it does in the case of ordinary light. The existence of this phenomenon was carefully verified and especial pains were taken by the author to prove that the result is not spurious. H. S. U.

6. *On the Mechanical Theory of the Vibrations of Bowed Strings and of Musical Instruments of the Violin Family, with Experimental Verification of the Results: Part I;* by C. V. Raman. Pp. iii, 158; 28 figures and 26 plates. Calcutta, 1918 (Bulletin No. 15. The Indian Association for the Cultivation of Science).—This monograph (which does not include all of Part I) is a very valuable contribution to the subject because purely empirical results have been eliminated by giving full mathematical explanations of all of the phenomena, from the simplest to the most complex, produced experimentally. "Not only does the theory succeed in explaining all the known phenomena but it has also justified itself by predicting many new relations and results which have been tested experimentally."

It is not possible to give an adequate idea of the scope of the investigation in a brief notice. Attention should be called, how-

ever, to the following points. The differential equations and the experimental curves take into account the mutual interactions of the belly, the bow, the bridge, and the string of the instrument. Thus the forcing of the bow coupled with the yielding of the bridge are subjected to analysis. The wolf-note pitch of the 'cello is given special attention and simultaneous curves are presented showing cyclical alternations in amplitude. The kinematical theory of the motion of bowed strings is discussed, and it is shown that when the bowed point is assumed to divide the string in an irrational ratio, the mode of vibration approaches one or other of certain ideal types which are completely defined by the motion of one, two, or more equal discontinuous changes of velocity moving along the string. In the detailed discussion of these "irrational" modes of vibration the remarkable result is obtained that if $n$, the number of discontinuities, be a *prime integer* greater than unity, a two-step zigzag motion is always possible at the bowed point except when this is at or near an end of the string: whereas, if $n$ be *not* a prime integer, the motion at the bowed point is necessarily of a more complicated type if it lies outside certain sections of the string. Not only is the subject presented in a lucid, rigorous and thorough manner but the reproductions of the photographs of the curves are beautiful from the esthetic as well as from the scientific point of view. H. S. U.

## II. Geology.

1. *United States Geological Survey;* George Otis Smith, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vols. **45**, pp. 475, 476; **47**, pp. 141, 142):

Topographic Atlas.—Thirty-nine sheets.

Folios.—No. 208 Colchester–Macomb Folio, Illinois; by Henry Hinds. In cooperation with the Geological Survey of Illinois. Pp. 14, 2 pls. of topography, 2 pls. of areal geology, 14 text figs.

Professional Papers.—No. 104. The genesis of the ores at Tonopah, Nevada; by E. S. Bastin and F. B. Laney. Pp. 50, 16 pls., 22 text figs.

No. 107. Geology and ore deposits of the Tintic mining district, Utah; by Waldemar Lindgren and G. F. Loughlin, with a historical review by V. C. Heikes. Pp. 282, 39 pls., 49 text figs.

No. 109. The Canning River region, northern Alaska; by E. de K. Leffingwell. Pp. 251, 35 pls., 33 text figs.

No. 110. A Geologic Reconnaissance of the Inyo Range and the eastern slope of the Sierra Nevada, Cal.; by Adolph Knopf,

with a section on the stratigraphy of the Inyo Range, by EDWIN KIRK. Pp. 130, 23 pls., 8 text figs.

No. 114. Geology and ore deposits of the Yerington district, Nevada; by ADOLPH KNOPF. Pp. 68, 5 pls., 12 text figs.

No. 120. Shorter contributions to general geology. Part F, by D. D. CONDIT. Part I by T. D. A. COCKERELL.

MINERAL RESOURCES of the United States, 1917. Numerous advance chapters.

BULLETINS.—No. 660. Contributions to Economic Geology, 1917. Part I, Metals and nonmetals except fuels; F. L. RANSOME, E. F. BURCHARD, and H. S. GALE, geologists in charge. Pp. 311, 11 pls., 33 text figs.

No. 664. The Nenana Coal Field, Alaska; by G. C. MARTIN. Pp. 54, 12 pls. including a map of central Alaska and a map of the Nenana coal field; also 10 township plats and coal maps.

No. 668. The Nelchina-Susitna region; by THEODORE CHAPIN. Pp. 67, 10 pls., 4 figs.

No. 676. Some Pliocene and Miocene Foraminifera of the coastal plain of the United States; by J. A. CUSHMAN. Pp. 100, 31 pls.

No. 677. Geology and mineral deposits of the Colville Indian Reservation, Washington; by J. T. PARDEE. Pp. 186, 12 pls., 1 text fig.

No. 680. A geologic reconnaissance for phosphate and coal in southeastern Idaho and western Wyoming; by A. R. SCHULTZ. Pp. 84, 2 pls.

No. 681. The oxidized zinc ores of Leadville, Colorado; by G. F. LOUGHLIN. Pp. 91, 8 pls., 7 text figs.

No. 685. Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colorado; by W. W. ATWOOD. Pp. 38, 8 pls., 17 text figs.

No. 686. Structure and oil and gas resources of the Osage Reservation, Oklahoma. Parts A, B, C, D, E, G.

No. 691. Contributions to Economic Geology. 1918. Part II. Mineral Fuels; DAVID WHITE, G. H. ASHLEY, and M. R. CAMPBELL, geologists in charge. Several advance chapters.

No. 593. The evaporation and concentration of waters associated with petroleum and natural gas; by R. VAN A. MILLS and ROGER C. WELLS. Pp. 104, 4 pls., 5 figs.

WATER-SUPPLY PAPER.—No. 410, 411. Surface water supply of the United States, 1915. Part X, N. C. GROVER, Chief Hydraulic Engineer. The Great Basin. Part XI, Pacific Slope Basins.

No. 422. Ground Water in the Animas, Playas, Hachita, and San Luis basins, New Mexico; by A. T. SCHWENNESEN, with analyses of water and soil, by R. F. HARE. Pp. 152, 9 pls., 17 text figs.

No. 425. Contributions to the hydrology of the United States. Parts B, E, D.

No. 427. Bibliography and Index of the publications of the U. S. Geological Survey relating to ground water; by OSCAR E. MEINZER. Pp. 169, with map in pocket (plate I).

2. *Publications of the U. S. Bureau of Mines;* VAN H. MANNING, Director.—Recent publications of the Bureau of Mines are as follows (see earlier, vol. **47**, p. 143):

BULLETINS: No. 144. Report of a joint committee appointed from the Bureau of Mines and the U. S. Geological Survey by the Secretary of the Interior to study the gold situation. Pp. 84, 1 pl., 3 figs.

No. 154. Mining and milling of lead and zinc ores in the Missouri-Kansas-Oklahoma zinc district; by C. A. WRIGHT. Pp. 134, 17 pls., 13 figs.

No. 161. California mining statutes annotated; by J. W. THOMPSON. Pp. 312.

No. 166. A preliminary report on the mining districts of Idaho; by THOMAS VARLEY, C. A. WRIGHT, E. K. SOPER, and D. C. LIVINGSTON. Pp. 112, 3 pls., 3 figs.

No. 169. Illinois mining statutes annotated; by J. W. THOMPSON. Pp. 594.

No. 170. Extinguishing and preventing oil and gas fires; by C. P. BOWIE. Pp. 48, 19 pls., 4 figs.

No. 172. Abstracts of current decisions on mines and mining, reported from January to May, 1918; by J. W. THOMPSON. Pp. 138.

No. 174. Abstracts of current decisions on mines and mining reported from May to September, 1918; by J. W. THOMPSON. Pp. 138.

No. 177. The decline and ultimate production of oil wells with notes on the valuation of oil properties; by C. H. BEAL. Pp. 84, 4 pls., 80 figs.

No. 179. Abstracts of current decisions on mines and mining, reported from September to December, 1918; by J. W. THOMPSON. Pp. 166.

Also numerous Technical Papers.

3. *Iowa Geological Survey;* GEORGE F. KAY, State Geologist. Bulletin No. 6. *The Raptorial Bird of Iowa;* by BERT H. BAILEY. Pp. 238, 93 figs. Des Moines, 1918.—Dr. Bailey, the author of this report, died on June 22, 1917, before it was entirely completed; fortunately, however, his student and co-worker, Miss Clementina Spencer, has been able to edit the work and make it complete for the press. This account of the hawks and owls of the State will be found especially valuable by the farmers and is only one of several practical reports which the Survey has issued (see also vol. **47**, p. 239).

4. *Virginia Geological Survey;* THOMAS L. WATSON, Director. Bulletin XVIII. *The geology and coal resources of Buchanan County*; by HENRY HINDS. In cooperation with the U. S.

Geological Survey. With a chapter on the *Forests of Buchanan County;* by W. G. SCHWAB. Pp. 278, 16 pls., 22 figs. Charlottesville (University of Virginia), 1918.—The county here described lies on the southeast border of the central part of the Appalachian coal field and is estimated to contain about 12,000,000,000 tons of high-grade, coking, bituminous coal in beds of minable thickness. Eighty per cent of the county is true forest land and it is notable that much of the chesnut has not yet been injured by the fungus blight which has been so disastrous farther north.

5. *Geological Survey of Illinois;* FRANK W. DEWOLF, Chief.—Recent publications include the following:

Bulletin No. 39. The environment of Camp Grant; by ROLLIN D. SALISBURY and HARLAN H. BARROWS. Pp. 75, 2 pls., 25 figs., 4 maps in pocket. Urbana, 1918.

Also, of the Cooperative Mining Series, Bulletins 23 and 24.

6. *North Carolina Geological and Economic Survey;* JOSEPH HYDE PRATT, State Geologist. Biennial report, 1917-18. Pp. 110. Raleigh, 1918.—Presents the results reached during the past two years with respect to geology and mineralogy, forestry, road work, hydrography, etc.

7. *Wisconsin Geological and Natural History Survey;* E. A. BIRGE, Director and W. O. HOTCHKISS, State Geologist.—Bulletin XLVII gives a reconnoissance soil survey of northeastern Wisconsin. It is accompanied by a separate series of soil maps belonging to bulletins XLVII to L.

8. *Om Skånes Brachiopodskiffer;* by GUSTAF T. TROEDSSON. Lunds Univ. Årsskrift, n. f., **15**, no. 3, 1918.—Following a concerted plan which might well be adopted by graduate students in American universities, the members of the Geological Field Club at Lund have set themselves the task of describing the geology of their province (Scania). Under the inspiring guidance of the late Dr. Moberg, their energetic professor, various students, among them Segerberg, Olin, Hede, Dr. Hadding, Westergard, Professor Grönwall, and now Troedsson, have produced a succession of valuable memoirs on the stratigraphy and paleontology of the Ordovician and Silurian.

The latest contribution describes in detail the stratigraphy and fauna of the Brachiopod shales (Upper Ordovician). Forty-one of the 46 species found had not previously been reported from these beds, and 21 are new. It is of interest to note that while the fauna as a whole is Ordovician, the author regards 5 of the species as prophetic of the Gotlandian, so that even where corals are absent, the late Ordovician contains recognizable Silurian elements. The ontogeny of *Dalmanites eucentrus* is described, and proves to be of unusual interest. The two plates present excellent figures of all the species. P. E. R.

## III. Miscellaneous Scientific Intelligence.

1. *Equilibrium and Vertigo;* by Isaac H. Jones, M.A., M.D. Pp. 15, 444. Philadelphia, 1918 (J. B. Lippincott Company, $5.00).—This book, bearing the stamp of approval of the Office of the Surgeon General of the Army of the United States, may be characterized by one quotation from the text; "It is only in the past few years that the function of the vestibular portion of the labyrinth has been carefully studied, preeminently by the Vienna group of otologists, to whom we are indebted for new methods of testing the internal ear." The book may in fact be regarded as the embodiment of the Vienna doctrine by the chief American apologist of the cult. To the quotation from Jones, one may be permitted to add a quotation from the preface to Huxley's "Anatomy of Vertebrated Animals": "I have intentionally refrained from burdening the text with references; and, therefore, the reader, while he is justly entitled to hold me responsible for any errors he may detect, will do well to give me no credit for what may seem original, unless his knowledge is such as to render him a competent judge on that head." Huxley's statement might be amplified somewhat to the effect that one should be extremely cautious in accepting the statements in the book as true unless his knowledge is sufficient to render him a competent judge on that head. This caution is the more necessary because of the numerous loose and even confusing or inaccurate statements to be found throughout the work. Taking our quotation above as one example, it may be pointed out that Erasmus Darwin and Purkinje, to go no further back, were well acquainted with rotation vertigo, and that the classical statement of its laws is that of Purkinje in 1820. Hitzig worked out the laws of galvanic vertigo in 1871 and brought them into line with the laws of rotation vertigo. Goltz and von Troeltsch were both familiar with the effects of incautious irrigation of the external auditory meatus with hot or cold water in 1870. The classical statement of the function of the vestibular, as distinguished from the cochlear or auditory, portion of the ear, is due to Alexander Crum Brown, Joseph Breuer and Ernst Mach in the early seventies. Brown's statement in 1876 of the function of the semicircular canal apparatus—the preception of the change of aspect of the head in space—is as good as any that has been made. The study of the relation of the central nervous system to the reactions to stimulation of or lesions of the vestibular portion of the ear has been of more recent date, but a surprisingly small amount of fundamental knowledge, compared with what is known, is due to the otologists of the modern Vienna school.

A misstatement of a more serious character is found on page 14. The physiologist and the neuroanatomist recognize that the

otic labyrinth belongs to the proprioceptors, and it is so deeply placed in the bone that it cannot be directly affected by surrounding objects. Crum Brown's statement of the function of the labyrinth takes no account of the relation of the individual to surrounding objects, and a little reflection will show that, contrary to the author's statement, the vestibular mechanism alone can give no knowledge whatever of the relation of the body to external objects. The relation of the body to external objects is known through the exteroceptive sense organs—the eye, the auditory portion of the ear and the other superficial sense organs.

The optimistic prophecy on page 24 "At the present hour perhaps the most valuable service that the otologist can render to the government is in the Aviation Service" has scarcely been justified by performance. I should, however, utter a warning that the failure of the so-called Vienna tests to produce anything of importance does not mean that the internal ear has no relation to the problem of aviation, or that something of value might not accrue from the application of other tests to a problem of a somewhat different nature. The contention of the author that the production of vertigo is dependent upon the integrity of the cerebellum, never resting upon more than a slender basis of fact, has been still further undermined by the observations on gunshot injuries of the cerebellum in the recent war. In this connection it may be mentioned that at least one exception to the statement on page 4, "nor does the cranial surgeon yet recognize the value of ear examinations in helping him to diagnosticate and locate intracranial lesions" is to be found in Cushing's volume "Tumors of the Nervus Acusticus and the Syndrome of the Cerebello-pontile Angle" published a year earlier.

Enough has been said to indicate that, on its scientific side at least, the book is scarcely suitable to place in the hands of immature and impressionable students. It is matter for regret that unsettled, to say nothing of unknown, matters are stated in a dogmatic way. It is still more regrettable that the book conveys the impression that it has the approval of the medical service of the army.

There are some good plates of the normal gross appearance of the brain and its various divisions, but the illustrations of pathological conditions, both gross and microscopic, are much inferior to those in Cushing's volume.

F. H. PIKE.

Department of Physiology,
Columbia University.

## OBITUARY.

DR. WILLIAM GILSON FARLOW, Professor of cryptogamic botany at Harvard University, and since 1895 an associate editor of this Journal, died on June 3 in his seventy-fifth year. A notice is deferred until a later number.

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[FOURTH SERIES.]

## ART. VII.—*The Ternary System $CaO-MgO-SiO_2$*; by J. B. FERGUSON and H. E. MERWIN.

CONTENTS.



### INTRODUCTION.

A number of investigations dealing with one or more of the four oxides, lime, alumina, magnesia and silica, have in recent years been carried out as preliminary steps in the laboratory study of rocks. To the results of these investigations which dealt with the three ternary systems, $CaO-Al_2O_3-SiO_2$, $CaO-MgO-Al_2O_3$, $MgO-Al_2O_3-SiO_2$ and parts of the fourth ternary system, $CaO-MgO-SiO_2$, we wish to add the results[1] of an investigation of the hitherto unknown parts of this last system and also to correlate these results with those previously obtained by others. Since but four ternary systems may be constructed from the four oxides, this investigation marks the completion of the series of studies of the solidus-liquidus relations in these ternary systems.

[1] A short preliminary summary of these results was published in Proc. Nat. Acad. Sci., 5, 16, 1919.

PREVIOUS INVESTIGATIONS.

A somewhat brief review of the results of the earlier workers in this field will be given. The component oxides will be considered first.

*Lime, CaO.*

The melting point of lime has been determined by Kanolt[2] as 2570°. Two crystalline modifications, both isometric, appear to exist;[3] the one found at ordinary temperatures has perfect cubic cleavage and a refractive index of 1·83.[4] In the ternary melts it has always appeared in rounded grains.[4]

*Magnesia (periclase), MgO.*

Kanolt[5] places the melting point of magnesia at 2800°C. Only one crystalline form is known, which is isometric, with perfect cubic cleavage and refractive index[6] of about 1·737. It has been observed in melts as rounded grains, sharp octahedrons or cuboctahedrons, and skeletal octahedrons.[7]

*Silica, $SiO_2$.*

The several crystalline forms of silica have been thoroughly investigated by C. N. Fenner.[8] Of these only tridymite and cristobalite occur as primary phases in this ternary system. *Tridymite* appears as thin plates[9] or platy aggregates[10] having refractive indices[11] of $\alpha = 1{\cdot}469$, $\gamma = 1{\cdot}473$.[12] *Cristobalite* appears as aggregates,[10] octahedra and cubes:[9] $\alpha = 1{\cdot}484$, $\gamma = 1{\cdot}487$.[8] It melts at $1710 \pm 10°$C.[12] The sluggish transition between cristo-

[2] J. Wash. Acad. Sci., **3**, 315, 1915.

[3] For summary of evidence see J. Wash. Acad. Sci., **5**, 567, 1915.

[4] Rankin and Wright, this Journal (4), **39**, 1, 1915; Sosman, Hostetter, and Merwin, J. Wash. Acad. Sci., **5**, 566, 1915.

[5] J. Wash. Acad. Sci., **3**, 315, 1915.

[6] Slight differences in refractive index indicate solid solution under some conditions. Mallard, Bull. Soc. Min. Fr., found 1·7364; Wright, this Journal (4), **28**, 325, found $1{\cdot}734 \pm {\cdot}002$; Sommerfeldt, Centralbl. Min. Geol. Pal., 1907, 213, found 1·7350. We have found 1·7375 for some fused magnesia of optical quality furnished by the Alundum Co. The dispersion of this sample follows: $C = 1{\cdot}7335$, $F = 1{\cdot}7475$.

[7] Definite crystals have been observed during this study. See also Rankin and Merwin, J. Am. Chem. Soc., **38**, 570, 1916.

[8] This Journal (4), **36**, 331, 1913.

[9] N. L. Bowen, this Journal (4), **38**, 245, 1914.

[10] G. A. Rankin and F. E. Wright, this Journal (4), **39**, 1, 1915.

[11] Fenner's values were confirmed by Schaller, when account is taken of the higher values—probably caused by solid solution—observed for this natural material. See note 12 below.

[12] J. B. Ferguson and H. E. Merwin, this Journal, **46**, 417, 1918.

balite and tridymite[13] takes place in this system below 1500°C.; for the pure substances Fenner's value is 1470 ± 10°C.

*The System lime-magnesia, CaO-MgO.*

In this system a simple eutectic relation exists. The eutectic composition is CaO 67, MgO 33, and its temperature about 2300°C. The diagram given by Rankin and Merwin[14] is partially reproduced in fig. 1.

*The System lime-silica, $CaO$-$SiO_2$.*

This system is somewhat more complicated. Four compounds are known to exist. They are the calcium metasilicate, the tricalcium disilicate, the calcium orthosilicate and the tricalcium silicate. The meta- and orthosilicates only are stable at their melting points and the tricalcium silicate does not even occur as a primary phase in this binary system. Two forms of the metasilicate, wollastonite and pseudowollastonite are known and also three forms of the orthosilicate. The temperature relations existing in this system are given in fig. 2 which is a corrected reproduction of the major part of the diagram given by Rankin and Wright.[15] The corrections deal with the melting point of cristobalite and the extent of the metasilicate solid solution.

The following are the optical properties observed for the phases in this binary system which occur in the ternary system.

*Pseudowollastonite,*[16] $\alpha CaO.SiO_2$; pseudohexagonal equant grains, polysynthetic twinning common: nearly uniaxial +, $\alpha = 1{\cdot}610$, $\beta = 1{\cdot}611$, $\gamma = 1{\cdot}654$; extinction angles small.

*Wollastonite,*[16, 17] $\beta CaO.SiO_2$; monoclinic, lath-shaped; cleavage parallel to elongation; $\alpha = 1{\cdot}616$, $\beta = 1{\cdot}629$, $\gamma = 1{\cdot}631$, 2E about 70°; extinction parallel, optic plane normal to cleavage lines.

*$3CaO.2SiO_2$;* probably orthorhombic, equant grains; $\alpha = 1{\cdot}641$, $\gamma = 1{\cdot}650$; + 2V large.

$\alpha$ *calcium orthosilicate,* $2CaO.SiO_2$, is stable from its

[13] This inversion is discussed on page 118 of this paper.
[14] G. A. Rankin and H. E. Merwin, J. Am. Chem Soc., **38**, 568, 1916.
[15] This Journal, 39, 1, 1915.
[16] For later observations, see pp. 91, 92.
[17] Day, Shepherd, Wright, this Journal **22**, 290-291, 1906.

FIG. 1.

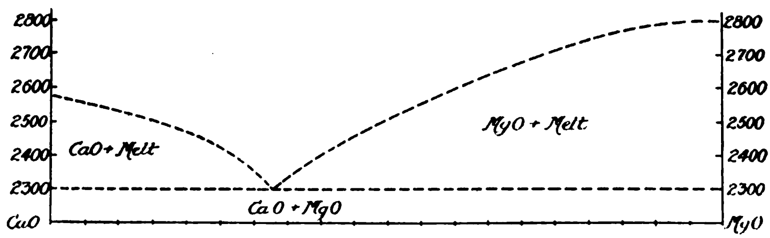



FIG. 1.—The binary system CaO-MgO. weight per cent.

FIG. 2.

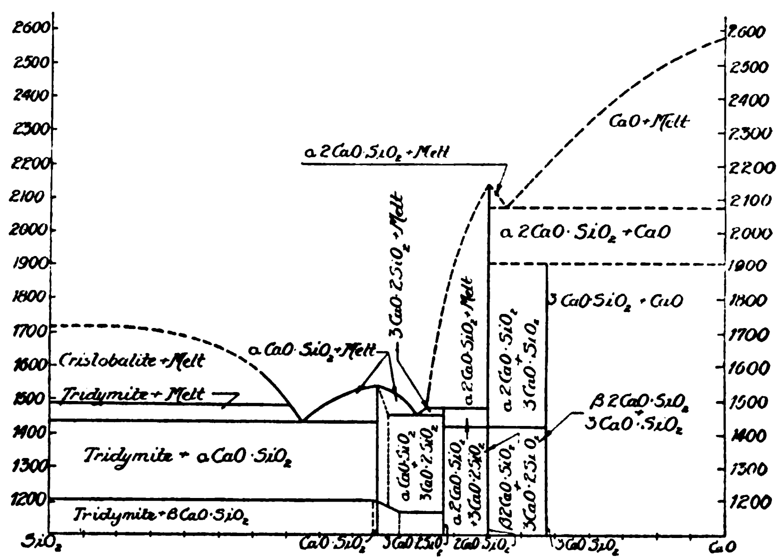



FIG. 2.—The binary system CaO-SiO₂. weight per cent.

FIG. 3.

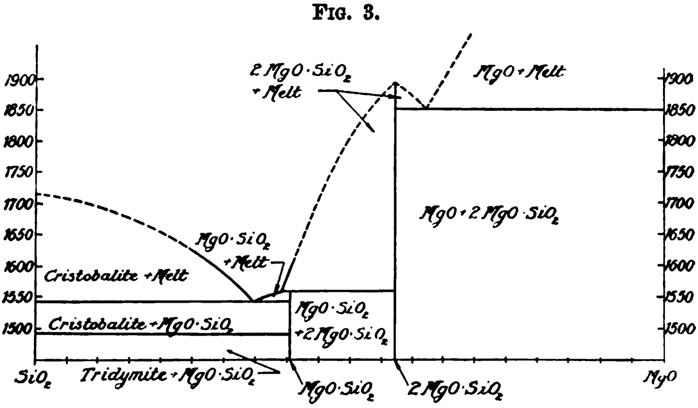



FIG. 3.—The binary system MgO-SiO₂. weight per cent.

melting point to 1420°.[18] The grains tend toward prismatic habit, are characteristically twinned, have + 2V large, $\alpha = 1{\cdot}715$, $\beta = 1{\cdot}720$, and $\gamma = 1{\cdot}737$.[19, 20]

*β calcium orthosilicate* is stable from 1420° to about 675°.[18, 23] The habit and optical properties are practically the same as for the α-form except that twinning is seldom present ($\alpha = 1{\cdot}717$, $\gamma = 1{\cdot}735$).[19, 21]

In the binary system $CaO$-$SiO_2$, the inversion α to β orthosilicate takes place promptly if the inversion temperature is passed through not very rapidly.[22]

*γ calcium orthosilicate* is stable below 675°.[23] It has prismatic habit, $\alpha = 1{\cdot}642$, $\beta = 1{\cdot}645$, $\gamma = 1{\cdot}654$, + 2V = about 60°.[24]

### *The System magnesia-silica, $MgO$-$SiO_2$.*

Two binary compounds occur in this system, the metasilicate and the orthosilicate. The former is unstable at its melting point, while the latter is stable. The temper-

FIG. 4.

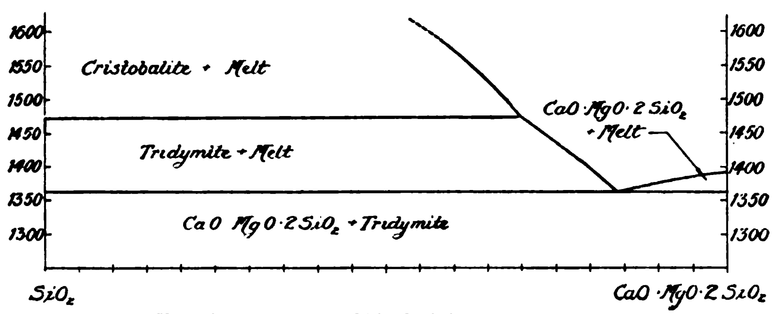



FIG. 4.—The binary system $SiO_2$-$CaO.MgO.2SiO_2$. wt. per cent.

[18] Rankin and Wright, this Journal, **39**, 76, 1915.

[19] Ibid., p. 7.

[20] Observations during the present study on crystals from various parts of the α orthosilicate field, confirm these data except that β is about 0·003 larger, and in some quenches scarcely a twinned grain could be found (see note 22), and the elongation may be either positive or negative.

[21] No accurate measurements of refractive index of this form were made during the present study.

[22] In most if not all of the quenches of the ternary system here considered which contained the α form as a primary phase, the α form has apparently persisted for many months. This is true unless either the criterion of twinning is not sufficient for distinguishing this form; or the inversion is like that of quartz at 575° and leaves no distinguishable optical effects. (See note 20.)

[23] Day, Shepherd and Wright, this Journal, **22**, 281, 1906.

[24] Corrected values (see note 19).

ature relations are shown in fig. 3. This is a reproduction of the diagram given by Bowen and Andersen[25] upon which the melting point of cristobalite has been corrected. The following descriptions of these compounds are given by the same investigators.

*Clino-enstatite, $MgO.SiO_2$,* Monoclinic; polysynthetic twinning after (100) is exceedingly characteristic.[26] The plane of the optic axis is normal to (010). The angle $\gamma_{\wedge}c = 22°$. Refractive indices: $\alpha = 1{\cdot}651$, $\gamma = 1{\cdot}660$.

FIG. 5.

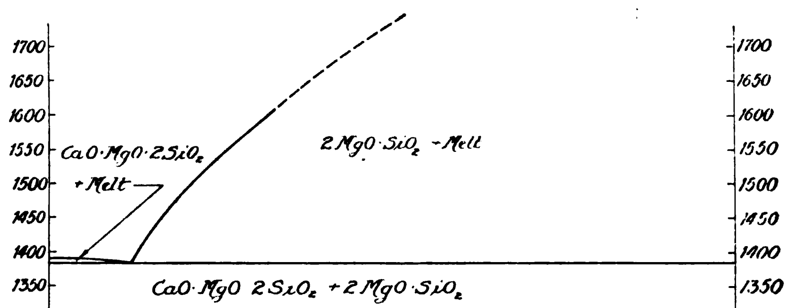



FIG. 5.—The binary system $2MgO.SiO_2$-$CaO.MgO.2SiO_2$. wt. per cent.

*Forsterite, $2MgO.SiO_2$.* $\alpha = 1{\cdot}635_1$, $\beta = 1{\cdot}651_0$, $\gamma = 1{\cdot}670$; $2V = 85°16'$. Optically positive.[27]

*Partial Studies of Ternary System $CaO$-$MgO$-$SiO_2$.*

Besides these binary systems dealing with the oxides, several systems have been studied which form part of the ternary system itself. (See fig. 5.) The first of these systems is the system $CaO.SiO_2$-$MgO.SiO_2$. This system may be divided into two parts, the ternary compound $CaO.MgO.2SiO_2$, called diopside, representing the point of division. Of the two resultant systems, the system $CaO.MgO.2SiO_2$-$MgO.SiO_2$ has been shown by Bowen to be not a true binary system and will be discussed when our later work is considered. The system $CaO.MgO.2SiO_2$-$CaO.SiO_2$ was first studied by Allen, White, Wright and Larsen[28] and their results were interpreted

[25] N. L. Bowen and Olaf Andersen, this Journal (4), 37, 487, 1914.

[26] In ternary melts with magnesia, twinning may be rare, this Journal, 45, 302, 1918.

[27] Allen, Wright, and Clement, this Journal, 22, 391, 1906.

[28] This Journal (4), 27, 1, 1909.

by Boeke.[29] The method used was that of heating curves (the quench method has not been perfected) and was scarcely adequate. Many curves were obtained which were susceptible of various interpretations. The most probable interpretation was based upon the assumption that the inversion temperature of the wollastonite was

FIG. 6.

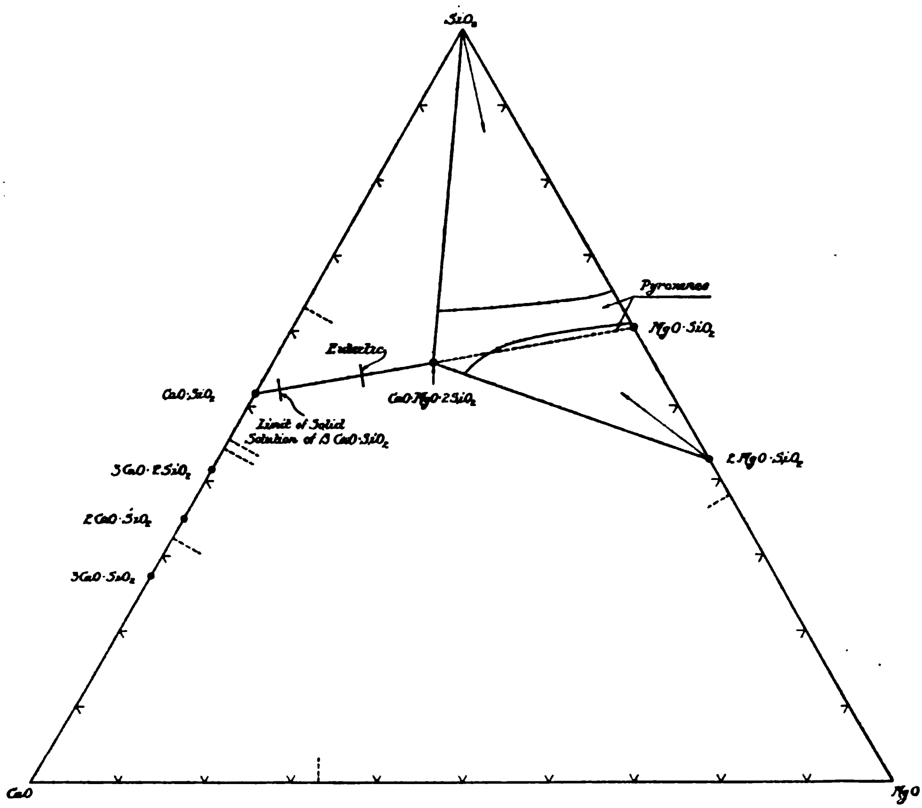



FIG. 6.—Partial ternary diagram showing the previously published results. wt. per cent.

never raised enough by solid solution to cause the solid solutions to appear as primary phases.

The chief optical properties observed for diopside are as follows:[30]

$\alpha = 1{\cdot}664\text{-}6$, $\beta = 1{\cdot}671\text{-}3$, $\gamma = 1{\cdot}694\text{-}5$; $+ 2V = 59°$; $\gamma_\wedge \dot{c} = 38\frac{1}{2}°$.

[29] Grundlagen der physikalisch-chemischen Petrographie, 182, 1915.
[30] Including new determinations.

The two systems $SiO_2$-$CaO.MgO.2SiO_2$ and $CaO.MgO.2SiO_2$-$2MgO.SiO_2$ have been studied by Bowen[31] as part of the ternary system diopside-forsterite-silica. They show simple eutectics, as may be seen in the diagrams given in figs. 4 and 5.

But in his ternary system Bowen found that there existed a complete series of solid solutions having diopside and clino-enstatite as end members.[32] Most of these solutions, like clino-enstatite, are unstable at their melting points. The rather complicated relations which obtain as a result of this somewhat unusual condition will not be discussed here but may be found in the original paper.

The concentration relations in these systems in so far as they affect the ternary system $CaO$-$MgO$-$SiO_2$ are collectively shown on the triangular diagram given in fig. 6 and form the starting point of the present investigation.

## General Procedure.

The initial step in a research of this character is the preparation of charges of known composition, and for this purpose chemically pure calcium carbonate, magnesium carbonate and silica were used. The magnesium carbonate was not used directly in this process but was first calcined in a platinum crucible in a Fletcher gas-blast furnace. After the ingredients were weighed out and thoroughly mixed in a mortar, the mixtures were fused in platinum crucibles and then reduced to a fine powder. This process was repeated two or three times to ensure complete homogeneity in the final product. Mixtures which fused completely at temperatures below 1500°C were heated in a platinum-resistance furnace; those melting at higher temperatures, in a Fletcher gas-blast furnace. When possible the compositions were finally prepared as glasses, since this form of material is necessary in many experiments and in addition may be easily tested under the microscope for homogeneity.

A few peculiarities were noted during the preparation of the compositions. Those lying within the silica field, unless they rapidly cooled, gave either milky or porcelain-like glasses. In the porcelain-like glasses in which the crystallization was further advanced, crystals of

[31] This Journal (4), 38, 207, 1914.
[32] See p. 92.

silica could be identified, but in the milky glasses the particles causing the milkiness could not be identified microscopically. In the charges very rich in silica this tendency to crystallize was accompanied by a great viscosity, so that relatively large crystals of cristobalite,

FIG. 7.

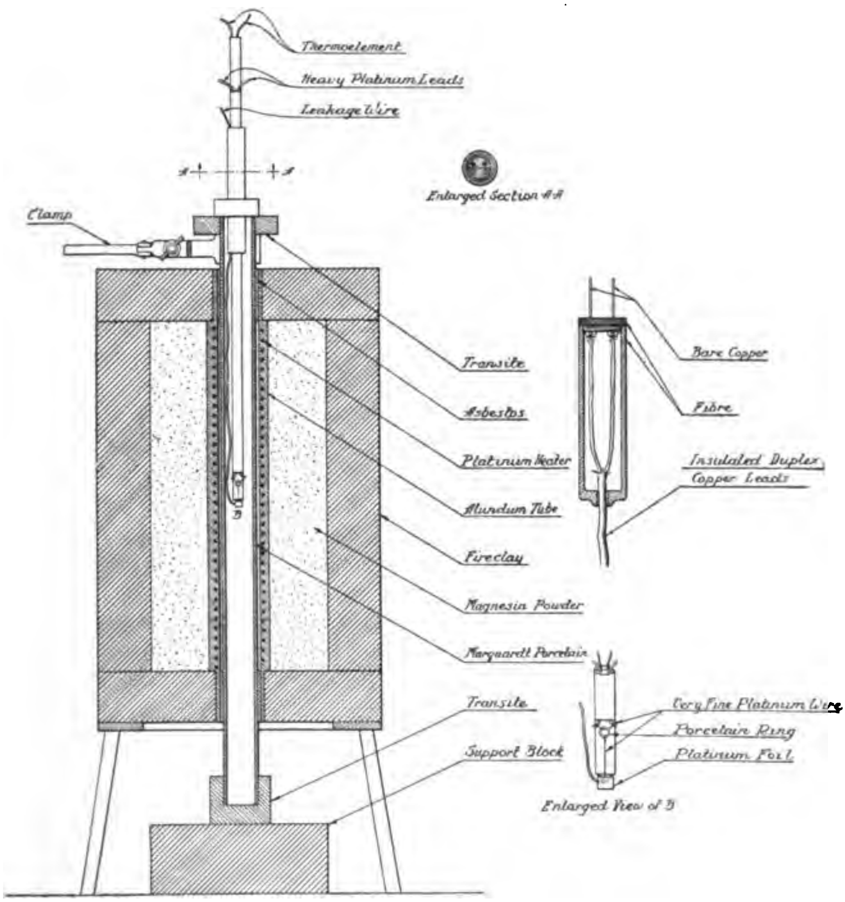



FIG. 7.—The quenching apparatus and furnace. (1) The furnace set up; (2) Enlarged views of parts of the quenching apparatus showing the method of insulating leads, etc., and the method of attaching the charge; (3) a longitudinal section of the device used to carry the copper leads by means of which a heavy current could be sent through the platinum leads to which the charge is attached and thus cause the charge to fall by fusing the supporting fine platinum wire. When this operation is to take place, the support block and transite cap are removed and a dish containing mercury is inserted beneath the marquardt porcelain tube in order to catch the charge and chill it instantly.

once formed, would dissolve but slowly, thus making almost impossible the preparation of homogeneous compositions. Compositions lying within the magnesia field showed a similar tendency to crystallize, and with these also, difficulty was experienced in obtaining homogeneity.

Once prepared, each composition was thoroughly investigated by means of the quenching method. This method consists in holding a small quantity of a given composition (called a "charge") at a given temperature long enough to insure the attainment of equilibrium and then chilling it suddenly without disturbing this equilibrium condition. The charge is wrapped in a small piece of platinum foil 0·01 m.m. thick which is attached to a thermoelement tube in such a manner as to be very near the junction, and is dropped into mercury by fusing the supporting wire by means of an electric current. The details of the method may be found in several of the preceding papers.[33] The apparatus is shown in fig. 7.

A few compositions, thoroughly investigated, served to locate approximately the various boundary lines, and with this information the efficient selection of the subsequent compositions was an easy task. Most of the charges required from 20 to 30 minutes to reach an equilibrium condition, but some charges, notably those in the $2CaO.MgO.2SiO_2$ field and those containing much silica, required a much longer treatment. Charges in which at equilibrium there was no glass, such as those used in the study of the wollastonite solid solutions, were heated for days before samples suitable for microscopic examination could be obtained. The formation of unstable pseudowollastonite crystals at temperatures below but near the inversion temperature took place readily when suitable glasses were crystallized at these temperatures. The inversion of pseudowollastonite to wollastonite does not take place readily and so when charges of wollastonite free from pseudowollastonite were desired, glasses were first crystallized at temperatures ranging from 800 to 900°C over long periods of time (15 hours) and this material if free from pseudowollastonite (in not more than one-half of the charges was this true) and from glass was then reheated at higher temperatures for some hours in order to let the crystals grow and enable a final selection of material to be made with certainty.

[33] See this Journal, 39, 1, 1915.

Charges within the monticellite ($CaO.MgO.SiO_2$) field, and in the forsterite field near it, crystallized with such rapidity that great difficulty was experienced in quenching them. The resorption of magnesia did not occur readily and charges selected for a study of this phenomenon were prepared in such a manner as to prevent the formation of large crystals of magnesia which if formed would not then dissolve in a reasonable time. The microscopic examinations were in part very troublesome. It often happened that the crystalline phases were not only very similar optically but also had nearly the same refractive index as the glass in which they were imbedded, thus making the positive identification of traces of either almost impossible.

## The Crystalline Phases.

The following crystalline phases[34] are found in the ternary system stable in contact with a suitable melt:

1. Lime, CaO.
2. Periclase, MgO.
3. Cristobalite and tridymite, $SiO_2$.
4. Pseudowollastonite, $\alpha CaO.SiO_2$.
5. $3CaO.2SiO_2$.
6. $\alpha 2CaO.SiO_2$ and $\beta 2CaO.SiO_2$.
7. Clino-enstatite, $MgO.SiO_2$.
8. Forsterite, $2MgO.SiO_2$.
9. Diopside, $CaO.MgO.2SiO_2$.
11. Åkermanite, $2CaO.MgO.2SiO_2$.
11. $5CaO.2MgO.6SiO_2$.
12. Monticellite ($CaO.MgO.SiO_2$)—forsterite solid solutions.
13. Wollastonite-diopside solid solutions.
14. Wollastonite-$5CaO.2MgO.6SiO_2$ solid solutions.

The significant properties of all of these phases with the exception of the compounds $5CaO.2MgO.6SiO_2$, and $2CaO.MgO.2SiO_2$ and the solid solutions of wollastonite, of $5CaO.2MgO.6SiO_2$, and of monticellite, have been given earlier in this paper and only corrections and such additional information as we have obtained will be given here.

*Pseudowollastonite* grows in remarkably large crystals as it forms during the inversion of wollastonite in the

[34] The general temperature-concentration relations of wollastonite, pseudowollastonite and $5CaO.2MgO.6SiO_2$ will be discussed in detail in a subsequent paper.

solid state, and the characteristic polysynthetic twinning with extinctions of 3° on either side is present. Solid solution represented by about 3 per cent magnesia does not appreciably change its optical properties, except to lower $\gamma$ about ·006.

*Wollastonite*: Crystals containing the maximum amount of diopside at the high temperatures (about 17 per cent) in solid solution had the following observed optical properties: $\alpha = 1{\cdot}619$, $\beta = 1{\cdot}631$, $\gamma = 1{\cdot}634$, $-2V = 40°$-$65°$. Mixcrystals of wollastonite and $5CaO.2MgO.6SiO_2$, and also $2CaO.MgO.2SiO_2$, have optical properties which are intermediate, so far as they have been determined. Crystals in the middle of the latter series are optically positive with large axial angle.

*$5CaO.2MgO.6SiO_2$*: Irregular, elongated grains, $\beta$ parallel to elongation; $\alpha = 1{\cdot}621$, $\beta = 1{\cdot}627$, $\gamma = 1{\cdot}635$, $+2V =$ about 80°.

*$2CaO.MgO.2SiO_2$*: Appears in stubby prisms occasionally have definite octagonal cross-section. Crystals from melts of various compositions have $\omega = 1{\cdot}631 \pm {\cdot}002$, $\epsilon = 1{\cdot}638 \pm {\cdot}002$. Frequently the crystals did not appear unless the melt was considerably undercooled. The relation of this compound to åkermanite is discussed later.

*Monticellite:* The crystals of monticellite appeared as equant grains without facets, and only optical and chemical relationships have been established between the crystals and the natural mineral. The observed values of $\alpha$ were 1·638 to 1·640, of $\beta$ 1·646, and of $\gamma$ 1·651 to 1·655; $+2V = 85°$ to 90°. These were obtained from five quenches at temperatures between 1400° and 1500°, having compositions ranging from 33 to 37 CaO, 21 to 28 MgO, and 39 to 42 $SiO_2$.

*Diopside:* The refractive indices of pure diopside were observed as follows: $\alpha = 1{\cdot}666$, $\gamma = 1{\cdot}695$.

*Diopside-clinoenstatite solid solutions* have not been studied further, but in the application of Mallard's formula to their extinction-angles volume per cent not mol. per cent should have been used.[35]

## Limits of the Fields of Stability.

Any charge with a composition in a ternary system similar to the one under investigation may be heated

[35] This Journal (4), 38, 248, 1914.

until it contains at equilibrium mere traces of crystalline matter immersed in a liquid. This crystalline material may consist of one, two or three phases. Compositions which under these conditions contain one crystalline phase will form an area; those which contain two crystalline phases will form a line, and those which contain three such phases will be points on a triangular concen-

FIG. 8.

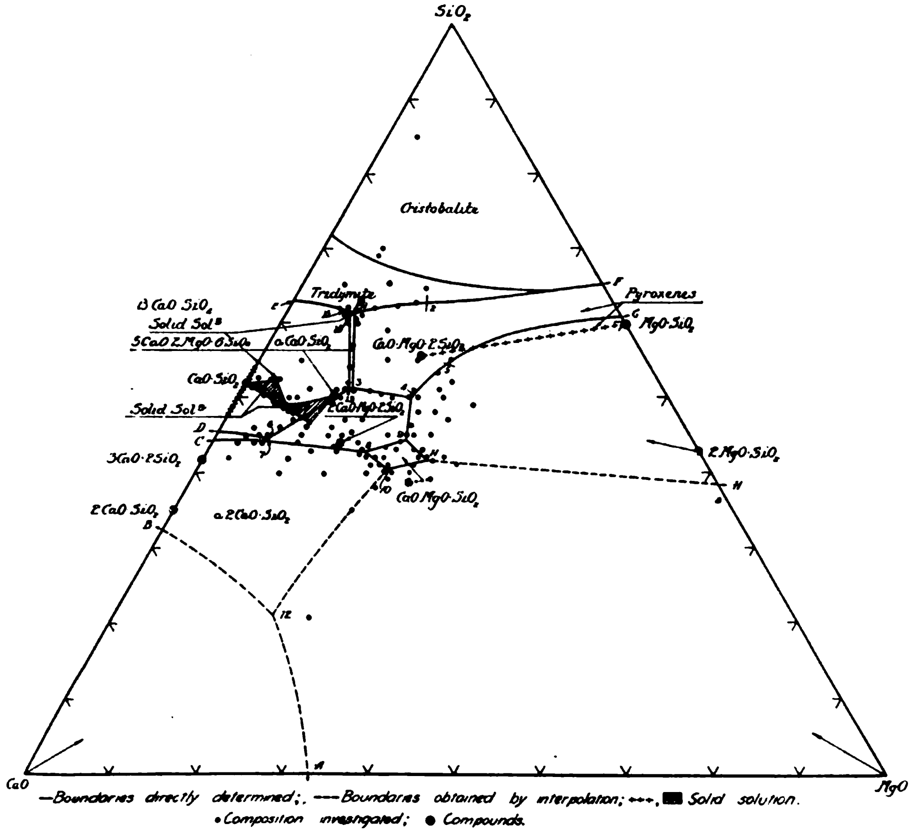



FIG. 8.—The triangular concentration diagram giving the compositions investigated and the limits of the fields of stability of the various phases in wt. per cent.

tration diagram. The area belonging to any crystalline phase is called its field of stability, and the lines and points just referred to represent the boundaries of the fields. The fields of stability and the compositions of the charges used to determine their limits are shown in fig. 8. Table I presents the results upon which this diagram is based.

TABLE I.

Quenches which locate the boundaries of the fields of stability.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present[36] | Boundary |
|---|---|---|---|---|---|---|
| 31 | 7 | 62 | 1343 | 20 | Glass + trace $SiO_2$ | 15, E |
| 32 | 6 | 62 | 1370 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| 23 | 14·5 | 62·5 | 1369 | 20 | Glass + trace $SiO_2$ | 1, 2 |
| 25·25 | 12·5 | 62·25 | 1350 | 20 | Glass + trace $SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 28 | 10 | 62 | 1343 | 20 | Glass + trace $SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 30 | 9 | 61 | 1327 | 15 | Glass + $CaO.MgO.2SiO_2$ | |
| 31 | 8·5 | 60·5 | 1327 | 25 | Glass + $CaO.MgO.2SiO_2$ | 1, 3 |
| 31 | 9 | 60 | 1334 | 15 | Glass + $CaO.MgO.2SiO_2$ | |
| 32 | 8 | 60 | 1344 | 30 | Glass + $\alpha CaO.SiO_2$ | |
| | | | 1340 | 20 | Glass + $5CaO.2MgO.6SiO_2$ + $CaO.MgO.2SiO_2$ | |
| 33 | 10 | 57 | 1350 | 20 | Glass + $5CaO.2MgO.6SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 35 | 11 | 54 | 1355 | 25 | Glass + $5CaO.2MgO.6SiO_2$ | |
| 32 | 8 | 60 | 1344 | 30 | Glass + $\alpha CaO.SiO_2$ | 13, 14 |
| | | | 1340 | 180 | Glass + $5CaO.2MgO.6SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 35 | 11 | 54 | 1355 | 25 | Glass + $5CaO.2MgO.6SiO_2$ | |
| 36 | 12 | 52 | 1368 | 25 | Glass + $\alpha CaO.SiO_2$ | |
| 32 | 7 | 61 | 1330-1335 | 240 | Glass + trace $SiO_2$ + $\beta CaO.SiO_2$ + $5CaO.2MgO.6SiO_2$ | 14, 16 |
| 30 | 20 | 50 | 1354 | 15 | No glass + $2CaO.MgO.2SiO_2$ + $CaO.MgO.2SiO_2$ | 3, 4 |
| | | | 1359 | 20 | All glass | |
| 32 | 18 | 50 | 1367 | 15 | Glass + $2CaO.MgO.2SiO_2$ | |
| 33 | 16·5 | 50·5 | 1366 | 20 | Glass + trace $2CaO.MgO.2SiO_2$ | |
| 34 | 15 | 51 | 1361 | 20 | Glass + trace $2CaO.MgO.2SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 36 | 13 | 51 | 1352 | 15 | Glass + trace $2CaO.MgO.2SiO_2$ | |
| 23 | 22·5 | 54·5 | 1385 | 20 | Glass + $CaO.MgO.2SiO_2$ | 4, 5 |
| 25 | 22 | 53 | 1388 | 20 | Glass + $2MgO.SiO_2$ | |
| 29 | 20 | 51 | 1367 | 15 | Glass + $CaO.MgO.2SiO_2$ | |
| 29 | 21 | 50 | 1365 | 20 | Glass + $2MgO.SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 37 | 12 | 51 | 1366 | 15 | Glass + trace $\alpha CaO.SiO_2$ | 13, 6 |
| 38 | 11 | 51 | 1366 | 25 | Glass + trace $\alpha CaO.SiO_2$ | |
| 38 | 12 | 50 | 1381 | 25 | Glass + $2CaO.MgO.2SiO_2$ | |
| 42·4 | 8·8 | 48·8 | 1403 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| 44 | 8·5 | 47·5 | 1406 | 20 | Glass + trace $2CaO.MgO.2SiO_2$ | |
| 45 | 8 | 47 | 1409 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| 47 | 7 | 46 | 1393 | 30 | Glass + trace $\alpha CaO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | |
| 47 | 8 | 45 | 1390 | 15 | Glass + $2CaOMgO.2SiO_2$ | |
| 49 | 6 | 45 | 1379 | 20 | Glass + $\alpha CaO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | |
| 50 | 5 | 45 | 1380 | 60 | Glass + $3CaO.2SiO_2$ | 6, D |
| 51·5 | 3·5 | 45 | 1417 | 10 | Glass + trace $\alpha CaO.SiO_2$ + trace $3CaO.2SiO_2$ | |
| 50 | 6 | 44 | 1389 | 15 | Glass + $2CaO.SiO_2$ | 7, C |
| 51 | 5 | 44 | 1410 | 15 | Glass + $2CaO.SiO_2$ | |

[36] The formulas of the pure compounds will be given to denote the phases, but in many cases the actual phases have not such compositions, being solid solutions and therefore variable in composition.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present[36] | Boundary |
|---|---|---|---|---|---|---|
| 53 | 3 | 44 | 1450 | 30 | Glass + $2CaO.SiO_2$ | 7, C |
| 49 | 7 | 44 | 1398 | 15 | Glass + trace $2CaO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | 7, 8 |
| 47 | 9 | 44 | 1426 | 15 | Glass + $2CaO.MgO.2SiO_2$ | |
| 46 | 10 | 44 | 1410 | 60 | Glass + $2CaO.MgO.2SiO_2$ | |
| 45 | 12 | 43 | 1450 | 20 | Glass + $2CaO.SiO_2$ | |
| 42 | 15 | 43 | 1450 | 30 | Glass + $2CaO.SiO_2$ | |
| 42 | 14·5 | 43·5 | 1448 | 15 | Glass + $2CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| | | | 1453 | 20 | Glass | |
| 39 | 18 | 43 | 1444 | 20 | Glass + $2CaO.MgO.2SiO_2$ | |
| 39·5 | 18 | 42·5 | 1449 | 35 | Glass + $2CaO.SiO_2$ | |
| 36 | 20·5 | 43·5 | 1438 | 15 | Glass + $CaO.MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | 8, 9 |
| | | | 1445 | 20 | Glass | |
| 34 | 22 | 44 | 1445 | 30 | Glass | |
| | | | 1439 | 30 | Glass + $CaO.MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 35 | 22 | 43 | 1473 | 20 | Glass + $CaO.MgO.SiO_2$ | |
| 31·5 | 22 | 46·5 | 1410 | 30 | Glass + $2MgO.SiO_2$ | 4, 9 |
| 33 | 22 | 45 | 1428 | 20 | Glass + $2MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| | | | 1432 | 15 | Glass | |
| 32 | 25 | 43 | 1477 | 15 | Glass + $2MgO.SiO_2$ | 9, 11 |
| 32 | 26 | 42 | 1501 | 60 | Glass + $2MgO.SiO_2$ | |
| 33 | 24 | 43 | 1472 | 15 | Glass + $CaO.MgO.SiO_2$ | |
| 33 | 25 | 42 | 1460 | 30 | Glass + $CaO.MgO.SiO_2$ | |
| 37 | 21 | 42 | 1467 | 15 | Glass + $CaO.MgO.SiO_2$ | 8, 10 |
| 37 | 22 | 41 | 1485 | 15 | Glass + $CaO.MgO.SiO_2$ | |
| 38 | 20 | 42 | 1483 | 15 | Glass + $CaO.MgO.SiO_2$ | |
| 38 | 21 | 41 | 1489 | 15 | Glass + $CaO.MgO.SiO_2$ + $2CaO.SiO_2$ | |
| | | | 1493 | 15 | Glass | |
| 38 | 22 | 40 | 1506 | 15 | Glass + $2CaO.SiO_2$ | |
| 39 | 19 | 42 | 1484 | 15 | Glass + $2CaO.SiO_2$ | |
| 39 | 20 | 41 | 1492 | 15 | Glass + $2CaO.SiO_2$ | |
| 34 | 25 | 41 | 1507 | 20 | Glass + MgO | 10, 11 |
| 37 | 23 | 40 | 1517 | 20 | Glass + MgO | |
| 38 | 23 | 39 | 1539 | 10 | Glass + MgO | 10, 12 |
| 40 | 22 | 38 | 1560 | 30 | Glass + MgO + trace $2CaO.SiO_2$ | |
| 44 | 21 | 35 | 1690 | 30 | Glass + trace MgO + trace $2CaO.SiO_2$ | |
| 31·5 | 27 | 41·5 | 1522 | 15 | Glass + MgO + $2MgO.SiO_2$ | 12, H |
| 30 | 28 | 42 | 1537 | 30 | Glass + $2MgO.SiO_2$ | |
| 29 | 30 | 41 | 1545 | 15 | Glass + MgO | |

The $\beta 2CaO.SiO_2$ field, if such a field exists, is too small to be shown upon the diagram. If no solid solution exists, it consists of that portion of the $2CaO.SiO_2$ field which lies below the isotherm[37] of 1420° since the inversion of the $\beta$ form to the $\alpha$ form in the pure compound occurs at this temperature. The points 14 and 16 lie too close to the point 15 to be separately located.

[37] See figure 12, beyond.

The limits of the lime field were obtained by interpolation. One quench at 1660°C of a charge with a composition lime 55, magnesia 25, silica 20, showed no glass and in it crystals of $2CaO.SiO_2$ and lime could be identified. If an equilibrium condition had been reached this indicates a eutectic relation between lime, magnesia and $\alpha 2CaO.SiO_2$ and this we have assumed to be true in making our diagrams. However, Rankin and Wright found that, in the binary system, lime and silica first gave rise to $2CaO.SiO_2$ and lime before combining to give $3CaO.SiO_2$, and a similar condition may have been encountered by us. If a eutectic exists (as we have assumed to be the case) the temperature of it must lie above 1900°C, the decomposition temperature of $3CaO.SiO_2$.

The heat treatment of charges in which the compound $2CaO.MgO.2SiO_2$ occurs as a primary or a secondary phase, as given in Table I, may seem to be far too short a time in view of the tendency shown by solutions of this compound to undercool. Such is, however, not the case, since if care be taken to start with fully crystallized material, and the temperature of the charge be never allowed to exceed the desired temperature, this difficulty can be and was avoided. In studies of this nature the length of the heat treatment of itself means but little unless the properties of the reacting phases are known and these may be of such a character as to necessitate a knowledge of the original state and previous history of each charge before one can judge if the heat treatment has been sufficient. The experiments carried out at temperatures above 1600°C were made in the cascade furnace[38] designed for the determination of the melting point of cristobalite.

## Temperature Relations along the Boundary Lines exclusive of Quintuple Points.

The temperatures at which the complete fusion of the charges with compositions represented by the boundary lines takes place, may be determined either directly upon such charges, or indirectly by following the crystallization curves of the compositions which lie within the adjacent fields. This latter method offers no especial

[38] J. B. Ferguson and H. E. Merwin, this Journal, 46, 417, 1918.

difficulty if solid solutions do not exist and the crystallization lines are straight lines, but if solid solutions exist these lines which represent the changes in the composition of the liquid in a charge during crystallization are curved, and since their curvature is often difficult to determine, in this case the method may be quite uncertain. In the ternary system under investigation there is much solid solution and for this reason most of the charges which were used for this part of the study lay close to the boundary lines in composition. The experimental results of this study are given in Table II.

TABLE II.

Quenches which determine the melting temperatures along the boundary lines.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present | Boundary |
|---|---|---|---|---|---|---|
| 32 | 6 | 62 | 1361 | 15 | Glass + $\alpha CaO.SiO_2$ + $SiO_2$ | 1, 16, 15, E |
| | | | 1370 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| | | | 1339 | 15 | Glass + $\alpha CaO.SiO_2$ + $SiO_2$ | |
| | | | 1334 | 20 | Glass + $\beta CaO.SiO_2$ + $SiO_2$ | |
| 32 | 7 | 61 | 1331 | 20 | Glass + $\beta CaO.SiO_2$ + $SiO_2$ | |
| | | | 1337 | 20 | Glass + $\alpha CaO.SiO_2$ | |
| 31 | 7 | 62 | 1343 | 20 | Glass + $SiO_2$ | |
| | | | 1338 | 20 | Glass + $SiO_2$ + $\alpha CaO.SiO_2$ | |
| 23 | 14·5 | 62·5 | 1370 | 20 | Glass + trace $SiO_2$ | 1, 2 |
| | | | 1365 | 25 | Glass + trace $SiO_2$ + $CaO.MgO.2SiO_2$ | |
| 25·25 | 12·5 | 62·5 | 1352 | 20 | Glass + $CaO.MgO.SiO_2$ | |
| | | | 1350 | 20 | Glass + $CaO.MgO.2SiO_2$ + $SiO_2$ | |
| 28 | 10 | 62 | 1349 | 30 | Glass | |
| | | | 1338 | 20 | Glass + $SiO_2$ + $CaO.MgO.2SiO_2$ | |
| 31 | 9 | 60 | 1326 | 15 | Glass + $CaO.MgO.2SiO_2$ | 1, 3 |
| | | | 1321 | 15 | Glass + $CaO.MgO.2SiO_2$ + $5CaO.2MgO.6SiO_2$ | |
| 32 | 8 | 60 | 1340 | 20 | Glass + trace $CaO.MgO.2SiO_2$ + trace $5CaO.2MgO.6SiO_2$ | |
| 33 | 10 | 57 | 1352 | 30 | Glass | |
| | | | 1350 | 20 | Glass + $5CaO. 2MgO.6SiO_2$ + $CaO.MgO.2SiO_2$ | |
| 35 | 11 | 54 | 1353 | 20 | Glass + $5CaO.2MgO.6SiO_2$ + $CaO.MgO.2SiO_2$ | |
| | | | 1356 | 25 | Glass + $5CaO.2MgO.6SiO_2$ | |
| 38 | 11 | 51 | 1361 | 30 | Glass + (trace $\alpha CaO.SiO_2$)* + $5CaO.2MgO.6SiO_2$ + trace $CaO.MgO.2SiO_2$ | 1, 3 |
| 36 | 12 | 52 | 1368 | 25 | Glass + $\alpha CaO.SiO_2$ | 13, 14, 15 |
| | | | 1363 | 25 | Glass + $\alpha CaO.SiO_2$ + $5CaO.2MgO.6SiO_2$ | |
| 32 | 8 | 60 | 1344 | | Glass + $\alpha CaO.SiO_2$ | |
| 36 | 12 | 52 | 1368 | | Glass + $\alpha CaO.SiO_2$ | |

(See also quenches 1, 3 above)

* $\alpha CaO.SiO_2$ is here unstable.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present | Boundary |
|---|---|---|---|---|---|---|
| 32 | 18 | 50 | 1365 | 20 | Glass + $CaO.MgO.2SiO_2$ + $2CaO.MgO.2SiO_2$ | 3, 4 |
| | | | 1371 | 20 | Glass + $2CaO.MgO.2SiO_2$ | |
| 33 | 16·5 | 50·5 | 1367 | 20 | Glass + $2CaO.MgO.2SiO_2$ | |
| | | | 1364 | 20 | Glass + $2CaO.MgO.2SiO_2$ + $CaO.MgO.2SiO_2$ | |
| 34 | 15 | 51 | 1361 | 20 | Glass + trace $2CaO.MgO.2SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 23 | 22·5 | 54·5 | 1383 | 20 | Glass + $CaO.MgO.2SiO_2$ | 4, 5 |
| | | | 1379 | 20 | No glass | |
| 25 | 22 | 53 | 1383 | 20 | Glass + trace $CaO.MgO.2SiO_2$ + $2MgO.SiO_2$ | |
| | | | 1388 | 20 | Glass + $2MgO.SiO_2$ | |
| 26 | 23 | 51 | 1375 | 20 | Glass + $2MgO.SiO_2$ + $CaO.MgO.2SiO_2$ | |
| | | | 1380 | 20 | Glass + $2MgO.SiO_2$ | |
| 29 | 21 | 50 | 1365 | 20 | Glass + $2MgO.SiO_2$ + trace $CaO.MgO.2SiO_2$ | |
| 50 | 5 | 45 | 1384 | 20 | Glass + $3CaO.2SiO_2$ | 6, D |
| | | | 1378 | 20 | Glass + $3CaO.2SiO_2$ + $\alpha CaO.SiO_2$ | |
| 51·5 | 3·5 | 45 | 1410 | 10 | Glass + $\alpha CaO.SiO_2$ + $3CaO.2SiO_2$ | |
| | | | 1417 | 10 | Glass + trace crystals | |
| 51 | 5 | 44 | 1404 | 15 | Glass + $2CaO.SiO_2$ + $3CaO.2SiO_2$ | 7, C |
| | | | 1410 | 15 | Glass + $2CaO.SiO_2$ | |
| 53 | 3 | 44 | 1430 | 15 | Glass + $2CaO.SiO_2$ + trace $3CaO.2SiO_2$ | |
| 37 | 12 | 51 | 1367 | 15 | Glass + $\alpha CaO.SiO_2$ | 3, 13, 6 |
| | | | 1362 | 15 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 38 | 12 | 50 | 1375 | 25 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| | | | 1381 | 25 | Glass + $2CaO.MgO.2SiO_2$ | |
| 42·4 | 8·8 | 48·8 | 1403 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| | | | 1398 | 15 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 44 | 8·5 | 47·5 | 1402 | 20 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| | | | 1406 | 20 | Glass + $2CaO.MgO.2SiO_2$ | |
| 45 | 8 | 47 | 1409 | 15 | Glass + $\alpha CaO.SiO_2$ | |
| | | | 1403 | 15 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 47 | 7 | 46 | 1393 | 30 | Glass + trace $\alpha CaO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | |
| 49 | 7 | 44 | 1405 | 15 | Glass + $2CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | 7, 8 |
| | | | 1410 | 15 | Glass | |
| 47 | 9 | 44 | 1422 | 15 | Glass + $2CaO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | |
| 45 | 12 | 43 | 1440 | 20 | Glass + $2CaO.SiO_2$ | |
| | | | 1432 | 15 | Glass + $2CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 42 | 14·5 | 43·5 | 1448 | 15 | Glass + $2CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| | | | 1453 | 15 | Glass | |
| 36 | 20·5 | 43·5 | 1445 | 20 | Glass | 8, 9 |
| | | | 1438 | 15 | Glass + $2CaO.MgO.2SiO_2$ + $CaO.MgO.SiO_2$ | |

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present | Boundary |
|---|---|---|---|---|---|---|
| 34 | 22 | 44 | 1445 | 30 | Glass | 8, 9 |
| | | | 1442 | 30 | Glass + $2CaO.MgO.2SiO_2$ + $CaO.MgO.SiO_2$ | |
| 39 | 18 | 43 | 1444 | 20 | Glass + $2CaO.MgO.2SiO_2$ | |
| | | | 1429 | 90 | No $2CaO.SiO_2$ | |
| 38 | 20 | 42 | 1436 | 20 | No $2CaO.SiO_2$ | |
| 33 | 22 | 45 | 1432 | 20 | Glass | 4, 9 |
| | | | 1428 | 15 | Glass + $2MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 32 | 23 | 45 | 1430 | 20 | Glass + $2MgO.SiO_2$ | |
| | | | 1423 | 15 | Glass + $2MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 31·5 | 22 | 46·5 | 1410 | 30 | Glass + $2MgO.SiO_2$ | |
| | | | 1406 | 25 | Glass + $2MgO.SiO_2$ + $2CaO.MgO.2SiO_2$ | |
| 30 | 22 | 48 | 1415 | 20 | Glass + $2MgO.SiO_2$ | |
| | | | 1392 | 30 | Glass + $2MgO.SiO_2$ + trace $2CaO.MgO.2SiO_2$ | |
| 34 | 25 | 41 | 1502 | 30 | Glass + MgO + $CaO.MgO.SiO_2$ | 10, 11 |
| | | | 1510 | 20 | Glass + MgO | |
| 35 | 25 | 40 | 1511 | 15 | Glass + MgO + $CaO.MgO.SiO_2$ | |
| | | | 1516 | 15 | Glass + MgO | |
| 38 | 21 | 41 | 1489 | 15 | Glass + $2CaO.SiO_2$ + $CaO.MgO.SiO_2$ | 8, 10 |
| | | | 1493 | 15 | Glass | |
| 40 | 22 | 38 | 1537 | 30 | Glass + MgO + trace $2CaO.SiO_2$ | 10, 12 |
| 44 | 21 | 35 | 1660 | 15 | Glass + MgO + $2CaO.SiO_2$ | |
| | | | 1690 | 30 | Glass + trace MgO + trace $2CaO.SiO_2$ | |
| 31·5 | 27 | 41·5 | 1529 | 20 | Glass | 11, H |
| | | | 1522 | 15 | Glass + MgO + $2MgO.SiO_2$ | |

The similarity between the optical properties of the monticellite crystals which contain in solution some forsterite and the forsterite crystals themselves is very marked, and for this reason the melting temperatures along the boundary line 9,11 in fig. 8 could not be determined except by the slope of the liquidus of the adjacent fields.

### The Quintuple Points.

Fourteen quintuple or invariant points at which three crystalline phases and a liquid can co-exist are to be found in this ternary system, and of these, six are true eutectics. These quintuple points are the points of intersection of three boundary lines and when the temperatures along each of three lines fall as they approach the point of intersection the point is called a eutectic.

Point 1, fig. 8, is a eutectic between diopside, tridy-

mite, and $5CaO.2MgO.6SiO_2$. It has a composition CaO 30·6, MgO 8, $SiO_2$ 61·4, and a temperature 1320 ± 5°C.

TABLE III.

Quenches which determine the temperature relations at point 1.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 31 | 7 | 62 | 1324 | 20 | Glass + crystals |
| | | | 1319 | 45 | No glass |
| 31 | 9 | 60 | 1321 | 15 | Glass + crystals |
| | | | 1316 | 15 | No glass |
| 32 | 7 | 61 | 1319 | 20 | No glass |
| | | | 1324 | 25 | Glass + crystals |
| 32 | 8 | 60 | 1315 | 20 | No glass |
| | | | 1320 | 20 | Glass + crystals |

Point 16 is a non-eutectic at which tridymite, a wollastonite solid solution, and a $5CaO.2MgO.6SiO_2$ solid solution can co-exist with a liquid. The temperature and location of this point have not been separately determined. It lies very close to point 15 with a probable temperature of 1330 ± 5°C.

Point 15 is a non-eutectic between pseudowollastonite, a wollastonite solid solution and tridymite. It occurs at the composition CaO 31·3, MgO 7·2, $SiO_2$ 61·5, and its temperature is 1335 ± 5°C.

TABLE IV.

Quenches which determine the temperature relations at point 15.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 31 | 7 | 62 | 1343 | 20 | Glass + $SiO_2$ |
| | | | 1338 | 20 | Glass + $SiO_2$ + $\alpha CaO.SiO_2$ |
| 32 | 6 | 62 | 1339 | 20 | Glass + $SiO_2$ + $\alpha CaO.SiO_2$ |
| | | | 1334 | 20 | Glass + $SiO_2$ + ($\beta CaO.SiO_2$ or $5CaO.2MgO.6SiO_2$) |
| 32 | 7 | 61 | 1331 | 20 | Glass + $SiO_2$ + ($\beta CaO.SiO_2$ or $5CaO.2MgO.6SiO_2$) |
| | | | 1337 | 20 | Glass + $\alpha CaO.SiO_2$ |

Point 14[39] is a quintuple point between pseudowollastonite, a wollastonite solid solution, and a $5CaO.2MgO.6SiO_2$ solid solution. It has a composition CaO 31·4, MgO 7·6, $SiO_2$ 61, and a temperature of 1340 ± 5°C.

Point 13 is a quintuple point between pseudowollaston-

[39] The location and temperatures of points 14 and 13 will be discussed under the wollastonite and $5CaO.2MgO.6SiO_2$ solid solutions.

ite, $5CaO.2MgO.6SiO_2$, and $2CaO.MgO.2SiO_2$. The composition is CaO 36·7, MgO 12·3, $SiO_2$ 51, and the temperature 1365 ± 5°C.

TABLE V.

Quenches which indicate the temperature relations at point 13.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 36 | 12 | 52 | 1368 | 25 | Glass + $\alpha CaO.SiO_2$ |
| | | | 1363 | 25 | Glass + $\alpha CaO.SiO_2$ + $5CaO.2MgO.6SiO_2$ |
| 38 | 11 | 51 | 1366 | 25 | Glass + $\alpha CaO.SiO_2$ + $5CaO.2MgO.6SiO_2$ |
| 37 | 12 | 51 | 1366 | 15 | Glass + $\alpha CaO.SiO_2$ |
| 38 | 12 | 50 | 1375 | 27 | Glass + $\alpha CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ |

Point 3 is a eutectic between $\alpha 5CaO.2MgO.6SiO_2$ solid solution, diopside and $2CaO.MgO.2SiO_2$. Its composition is CaO 36, MgO 12·6, $SiO_2$ 51·4, and its temperature 1350 ± 5°C.

TABLE VI.

Quenches which determine the temperature relations at point 3.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 36 | 13 | 51 | 1345 | 30 | No glass |
| | | | 1350 | 30 | Glass + $5CaO.2MgO.6SiO_2$ + $CaO.MgO.2SiO_2$ + $2CaO.MgO.2SiO_2$ |
| | | | 1354 | 120 | Glass + crystals |
| | | | 1348 | 120 | Crystals + merest trace if any of glass |
| 37 | 12 | 51 | 1351 | 20 | All crystals |
| | | | 1353 | 30 | Glass + crystals |

Point 4 is a eutectic between $2CaO.MgO.2SiO_2$, forsterite and diopside. The composition is CaO 29·8, MgO 20·2, $SiO_2$ 50, and the temperature 1357 ± 5°C.

TABLE VII.

Quenches which determine the temperature relations at point 4.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 29 | 21 | 50 | 1354 | 30 | No glass |
| | | | 1359 | 20 | Glass + crystals |
| 30 | 20 | 50 | 1354 | 15 | No glass |
| | | | 1359 | 20 | All glass |

Point 6 is a eutectic between pseudowollastonite, $3CaO.2SiO_2$ and $2CaO.MgO.2SiO_2$. Its composition is CaO 49·2, MgO 6·3, $SiO_2$ 44·5, and its temperature 1377 ± 5°C.

TABLE VIII.

Quenches which determine the temperature relations at point 6.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 49 | 6 | 45 | 1374 | 20 | No glass |
| | | | 1379 | 20 | Glass + crystals |
| 50 | 5 | 45 | 1378 | 20 | Glass + crystals |
| | | | 1374 | 20 | No glass |
| 49 | 7 | 44 | 1375 | 15 | No glass |
| | | | 1384 | 15 | Glass + crystals |

Point 7 is a quintuple point between $\beta 2CaO.SiO_2$, $3CaO.2SiO_2$ and $2CaO.MgO.2SiO_2$. The composition is CaO 49·5, MgO 6·2, $SiO_2$ 44·3, and the temperature is 1387 ± 5°C.

TABLE IX.

Quenches which determine the temperature relations at point 7.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 49 | 7 | 44 | 1384 | 15 | Glass + $3CaO.2SiO_2$ + $2CaO.MgO.2SiO_2$ |
| | | | 1389 | 15 | Glass + $2CaO.SiO_2$ + $2CaO.MgO.2SiO_2$ |
| 50 | 6 | 44 | 1391 | 15 | Glass + $2CaO.SiO_2$ + $3CaO.2SiO_2$ |
| | | | 1384 | 15 | Glass + $2CaO.MgO.2SiO_2$ + $3CaO.2SiO_2$ |

Point 8 is a eutectic between $2CaO.MgO.2SiO_2$, $\alpha 2CaO.SiO_2$ and a monticellite solid solution. Its composition is CaO 39, MgO 18·3, $SiO_2$ 42·7, and its temperature 1436 ± 5°C.

TABLE X.

Quenches which determine the temperature relations at point 8.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 39 | 19 | 42 | 1443 | 20 | Glass + crystals |
| | | | 1436 | 20 | No glass |
| | | | 1443 | 60 | Glass + crystals |
| | | | 1438 | 45 | No glass, crystals including $2CaO.SiO_2$ |
| 39·5 | 18 | 42·5 | 1443 | 30 | Glass + crystals |
| | | | 1438 | 20 | Glass + crystals |
| | | | 1432 | 15 | No glass, crystals including $2CaO.SiO_2$ |

Point 9 is a quintuple point between $2CaO.MgO.2SiO_2$, forsterite, and a monticellite solid solution. Its composition is CaO 33·3, MgO 22·3, $SiO_2$ 44·4, and its temperature 1436 ± 5°C.

TABLE XI.

Quenches which determine the temperature relations at point 9.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 33 | 24 | 43 | 1439 | 20 | Glass + $2MgO.SiO_2$ + $CaO.MgO.SiO_2$ + No $2CaO.MgO.2SiO_2$ |
| | | | 1434 | 20 | Glass + $2CaO.MgO.2SiO_2$ + $2MgO.SiO_2$ |
| 34 | 22 | 44 | 1439 | 30 | Glass + $2CaO.MgO.2SiO_2$ + $CaO.MgO.SiO_2$ |
| | | | 1434 | 35 | Glass + $2CaO.MgO.2SiO_2$ + $2MgO.SiO_2$ |

Point 10 is a quintuple point between periclase, a monticellite solid solution and $\alpha 2CaO.SiO_2$. It has a composition CaO 37·3, MgO 22·3, $SiO_2$ 40·3, and a temperature 1498 ± 5°C.

TABLE XII.

Quenches which determine the temperature relations at point 10

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 37 | 23 | 40 | 1494 | 20 | Glass + $2CaO.SiO_2$ + $CaO.MgO.SiO_2$ |
| | | | 1500 | 25 | Glass + trace MgO + $CaO.MgO.SiO_2$ |
| 38 | 22 | 40 | 1503 | 10 | Glass + MgO + $2CaO.SiO_2$ |
| | | | 1498 | 20 | Glass + $2CaO.SiO_2$ + $CaO.MgO.SiO_2$ |

Point 11 is a quintuple point between periclase, forsterite and a monticellite solid solution. Its composition is CaO 32·1, MgO 26·4, $SiO_2$ 41·5, and its temperature 1502 ± 5°C.

TABLE XIII.

Quenches which determine the temperature relations at point 11.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 31·5 | 27 | 41·5 | 1499 | 25 | Glass + $2MgO.SiO_2$ + $CaO.MgO.SiO_2$ + No MgO |
| | | | 1507 | 25 | Glass + MgO + $2MgO.SiO_2$ |
| 32 | 26 | 42 | 1496 | 15 | Glass + $2MgO.SiO_2$ + $CaO.MgO.SiO_2$ |
| 30 | 28 | 42 | 1500 | 25 | No MgO + ? |
| | | | 1508 | 15 | MgO + ? |

Point 12 is a eutectic[40] between periclase, lime and $\alpha 2CaO.SiO_2$. Its composition and temperature are uncertain since the latter lies above the working temperatures of either of our furnaces and the rapidity with which $\alpha 2CaO.SiO_2$ and periclase both crystallize precluded the

[40] See the discussion of the lime field following Table I.

use of the iridium furnace, but the temperature probably lies above 1900°C, the temperature at which the tricalcium silicate decomposes into lime and $\alpha 2CaO.SiO_2$.

The exact temperature relations at the quintuple points, at the quadruple points on the side lines, and along the boundary lines, may be depicted by constructing a model which has as a base the concentration diagram, fig. 8, and upon which the temperatures are shown as vertical dis-

Fig. 9.

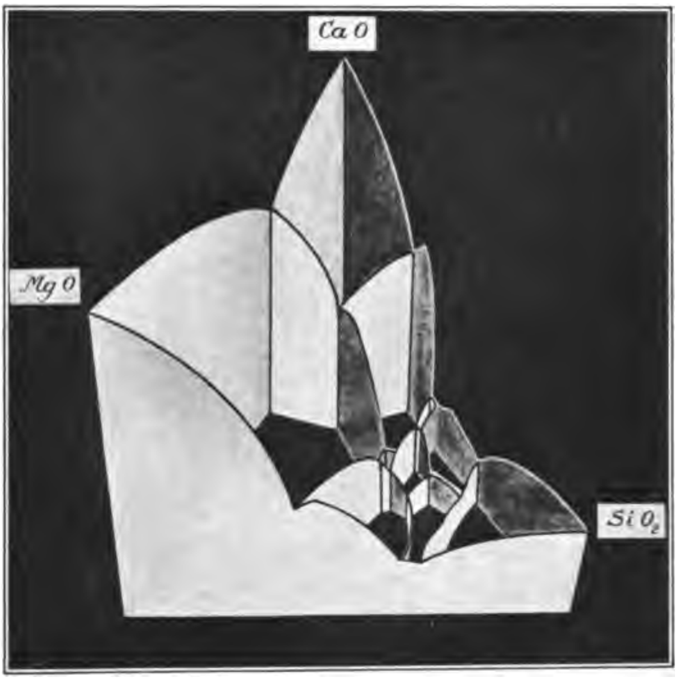



Fig. 9.—A model constructed by plotting vertically upon the concentration diagram as given in fig. 8, the temperature of complete fusion of the compositions lying along the boundaries of the fields of stability of the various phases.

tances above this base. Fig. 9 is a photograph of such a model.[41] This particular model includes and correlates the previous results of Bowen on this ternary system,

[41] This is the framework of a solid model. A description of the constructional details of such a model is given by Rankin and Wright, this Journal, **39**, 1, 1915.

FIG. 10*a*.

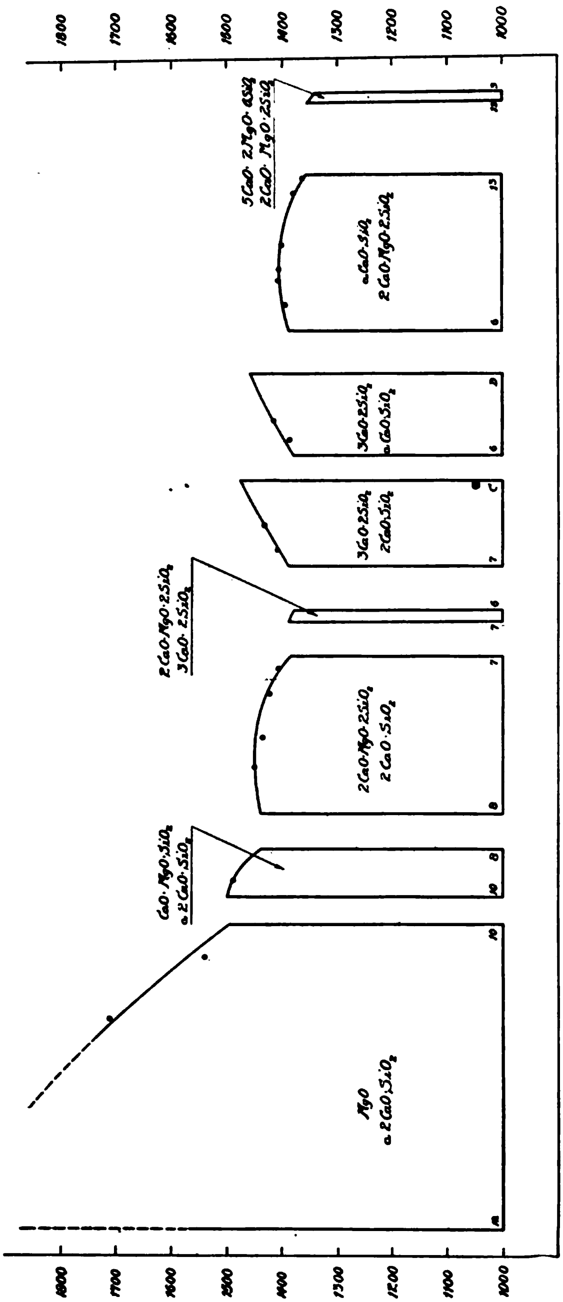



FIG. 10*a*.—The vertical projections of the boundary lines shown in fig. 9 which indicate the temperature relations along these lines.

FIG. 10b.

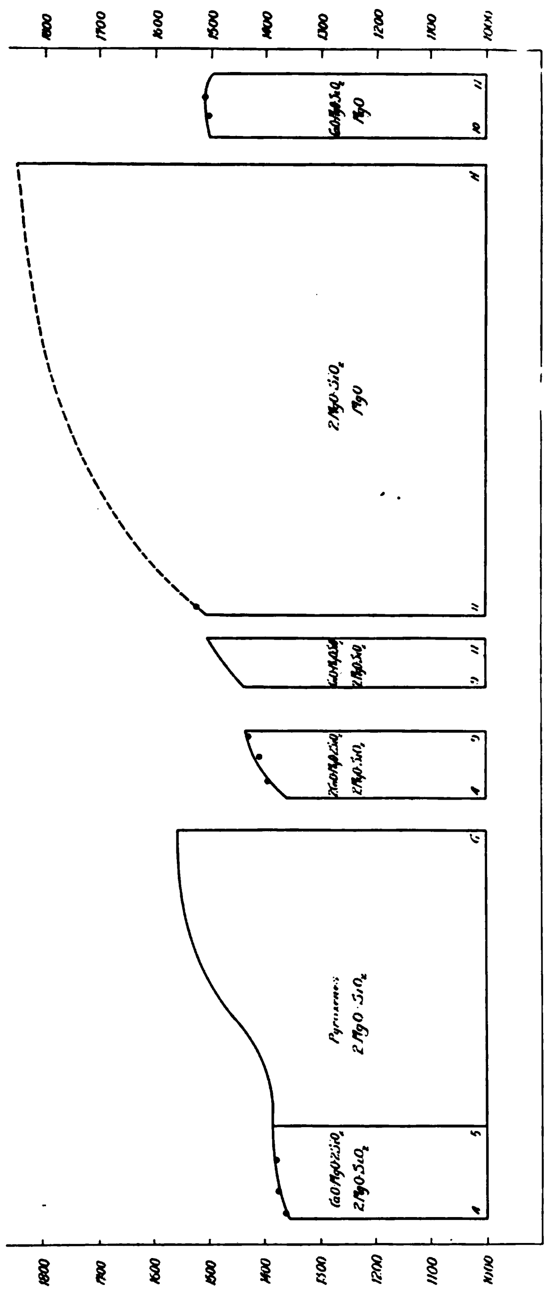



FIG. 10b.—The vertical projections of the boundary lines shown in fig. 9 which indicate the temperature relations along these lines.

FIG. 10c.

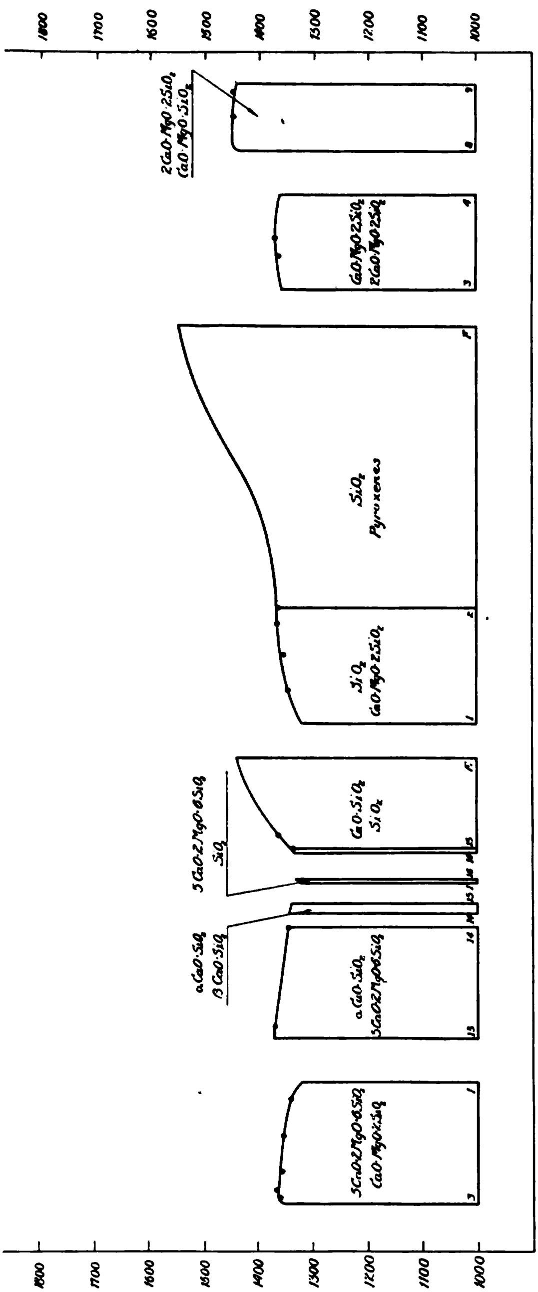



FIG. 10c.—The vertical projections of the boundary lines shown in fig. 9 which indicate the temperature relations along these lines.

with our results given in Tables II–XIII, inclusive, in addition to the results of the various investigators on the side-line binary systems. A vertical projection of

Fig. 11.

Fig. 11.—The complete temperature concentration diagram which was constructed by plotting vertically upon the concentration diagram given in fig. 8 the temperatures of complete fusion of the various compositions.

each of the lines within the ternary system is given in figs. 10 (a, b and c), and perhaps shows these relations more clearly than does the model itself.

These curves are also of interest because they serve as

a check upon the experimental methods employed. The curves 1F and 4G are perhaps the best illustrations of what reliance may be placed upon the methods. Each of these curves represents the work of several investi-

FIG. 12.

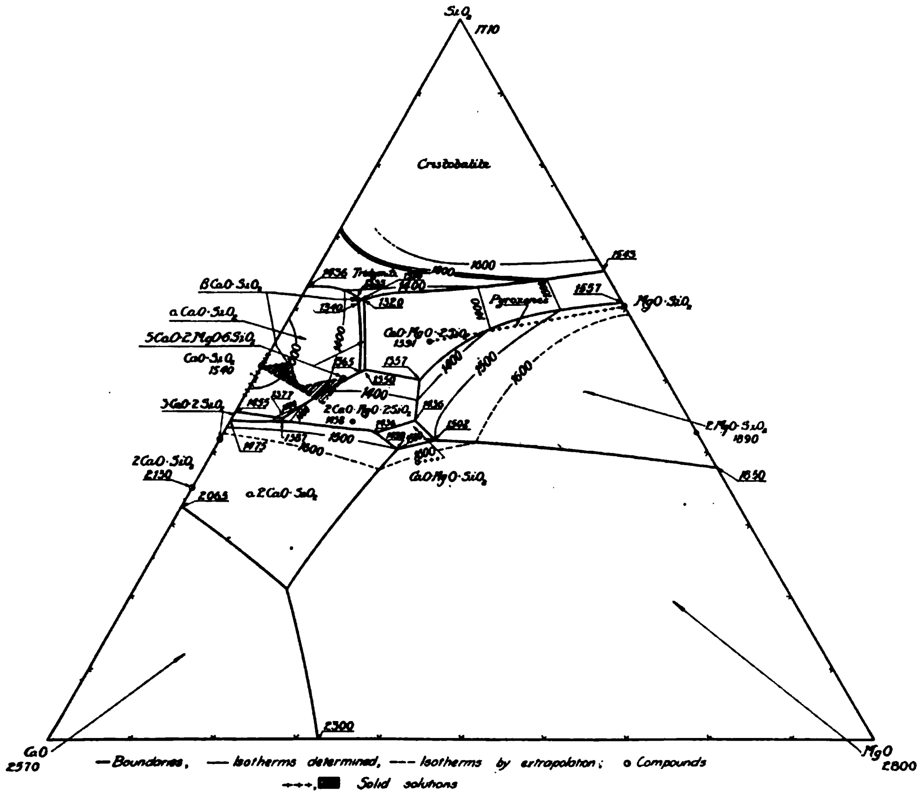



FIG. 12.—A concentration diagram somewhat similar to that given in fig. 8 upon which the isotherms showing the temperatures of complete melting of the various compositions are drawn. The diagram is on a wt. per cent basis.

gators; 2, F, and 5, G were determined by N. L. Bowen, 1, 2, and 4, 5, by ourselves. The agreement here obtained is of the order usually found between experiments of the same series, but in this case somewhat exceeds that usually obtained by us when the identical apparatus was not used for all experiments. A somewhat similar

agreement was found between the concentration relations, and this fact may readily be gleaned from an inspection of figs. 6 and 8.

A maximum is shown on the line 8, 9, although it has not been experimentally determined, the line 8, 9 being

FIG. 13.

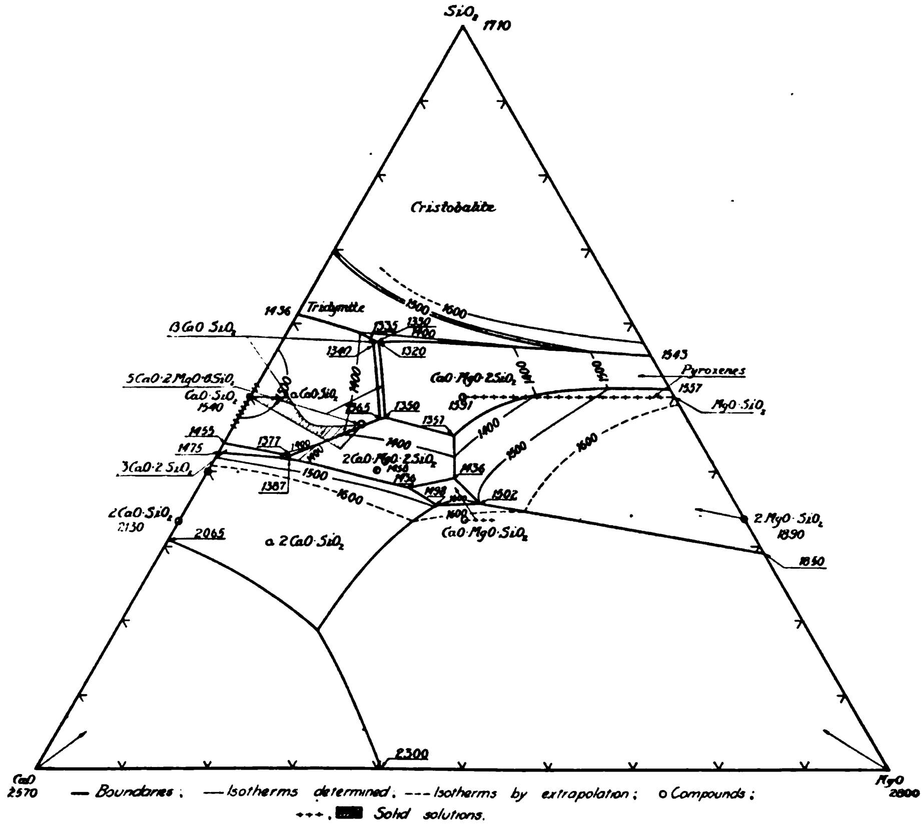



FIG. 13.—A similar diagram to that shown in 12 except that it is on a mol. per cent basis. With this exception this paper has been written upon a wt. per cent basis.

too flat. The reasons for placing a maximum here will be discussed under the monticellite solid solutions, and similarly the peculiar relations exhibited by the lines 1, 3 and 13, 14, 15 will be discussed under the wollastonite solutions.

## The Melting Temperatures Within the Fields.

The temperatures at which charges with compositions lying within the fields become completely fused are given in Tables XIV–XXI, inclusive.

### Table XIV.

Melting temperatures in the silica field: Melting point of cristobalite 1710 ± 10°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 23 | 7 | 70 | 1675 | 120 | Glass |
| previous charge reheated | | | 1638 | 30 | Glass + crystals |
| 23 | 14·5 | 62·5 | 1375 | 20 | Glass + trace crystals |
| 25 | 10 | 65 | 1485 | 45 | Glass |
| | | | 1472 | 15 | Glass + trace crystals |
| 26 | 7 | 67 | 1546 | 10 | Glass |
| | | | 1536 | 10 | Glass + crystals |
| 30 | 5 | 65 | 1463 | 15 | Glass + crystals |
| | | | 1472 | 10 | Glass |
| 31 | 7 | 62 | 1347 | 20 | Glass |
| | | | 1343 | 20 | Glass + trace crystals |

### Table XV.

Melting temperatures in the diopside field; melting point of diopside 1391°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 28 | 13 | 59 | 1375 | 10 | Glass |
| | | | 1370 | 10 | Glass + crystals |
| 30 | 15 | 55 | 1375 | 15 | Glass + crystals |
| | | | 1381 | 10 | Glass |

The melting temperatures of compositions lying within the fields of the $\beta CaO.SiO_2$ or wollastonite solid solutions and the $5CaO.2MgO.6SiO_2$ solid solutions must be obtained from the temperatures of the boundaries, as the fields are too narrow to warrant an investigation.

### Table XVI.

Melting temperatures in the $\alpha CaO.SiO_2$ field; melting point of $\alpha CaO.SiO_2$ 1540°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 32 | 6 | 62 | 1370 | 15 | Glass + trace crystals |
| 35 | 5 | 60 | 1402 | 10 | Glass |
| | | | 1395 | 10 | Glass + crystals |
| 40 | 5 | 55 | 1468 | 10 | Glass + trace crystals |

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 45 | 5 | 50 | 1476 | 10 | Glass |
| | | | 1468 | 15 | Glass + crystals |
| 46·7 | 3·1 | 50·2 | 1490 | 15 | Crystals + trace glass? |
| | | | 1500 | 15 | Glass |
| 44·3 | 2·8 | 52·4 | 1500 | 15 | Trace glass + crystals |
| | | | 1510 | 15 | Glass + trace crystals |
| 44 | 6 | 50 | 1470 | 15 | Glass + trace crysals |

TABLE XVII.

Melting temperatures in the $2CaO.MgO.2SiO_2$ field; melting point of $2CaO.MgO.2SiO_2$ 1458 ± 5°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 35 | 20 | 45 | 1446 | 10 | Glass |
| | | | 1440 | 10 | Glass + crystals |
| 39 | 14 | 47 | 1431 | 20 | Glass + trace crystals |
| 39 | 15·5 | 45·5 | 1440 | 10 | Glass + crystals |
| | | | 1445 | 10 | Glass |
| 39 | 17 | 44 | 1449 | 20 | Glass + crystals |
| | | | 1454 | 20 | Glass |
| 39 | 18 | 43 | 1450 | 20 | Glass |
| | | | 1444 | 20 | Glass + crystals |
| 40·33 | 14·66 | 45 | 1455 | 5 | Glass |
| | | | 1450 | 10 | Glass + crystals |
| 41 | 13 | 46 | 1434 | 20 | Glass |
| | | | 1430 | 20 | Glass + crystals |
| | | | 1459 | 20 | Glass |
| 41 | 15 | 44 | 1456 | 15 | Crystals only |
| $2CaO.MgO.2SiO_2$ | | | 1460 | 10 | Glass |
| | | | 1455 | 10 | Crystals only |

The phase $3CaO.2SiO_2$ is unstable at its melting point and its field is too small to warrant the determination of melting temperatures within it, other than by interpolation from the boundaries.

The phase $\alpha 2CaO.SiO_2$ melts at 2130 ± 10°C and the temperature gradient within its field is so steep that but few melting temperatures were determined.

TABLE XVIII.

Melting temperatures within the $2CaO.SiO_2$ field. Melting point of $\alpha 2CaO.SiO_2$ 2130 ± 10°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 48 | 10 | 42 | 1547 | 10 | Glass + trace crystals |
| 45 | 12 | 43 | 1470 | 15 | Glass + crystals |
| | | | 1475 | 15 | Glass |
| 40 | 20 | 40 | 1546 | 10 | Glass |
| | | | 1536 | 10 | Glass + crystals |

The phase $CaO.MgO.SiO_2$ is unstable at its melting point and in addition is variable in composition since it belongs to a series of solid solutions of forsterite in pure monticellite.

TABLE XIX.

Melting temperatures within the monticellite field.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 33 | 25 | 42 | 1502 | 16 | Glass + crystals |
| | | | 1509 | 16 | Glass |
| 35 | 22 | 43 | 1478 | 15 | Glass |
| | | | 1473 | 15 | Glass + crystals |
| 37 | 21 | 42 | 1483 | 15 | Glass |
| | | | 1467 | 15 | Glass + crystals |
| 37 | 22 | 41 | 1497 | 15 | Glass |
| | | | 1487 | 15 | Glass + crystals |
| 38 | 20 | 42 | 1489 | 18 | Glass |
| | | | 1483 | 15 | Glass + crystals |

TABLE XX.

Melting temperatures within the periclase field, the melting point of periclase 2800 ± 20°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 34 | 25 | 41 | 1515 | 20 | Glass + trace MgO |
| 35 | 25 | 40 | 1539 | 10 | Glass |
| | | | 1528 | 10 | Glass + crystals |
| 37 | 23 | 40 | 1521 | 20 | Glass |
| | | | 1517 | 20 | Glass + crystals |

TABLE XXI.

Melting temperatures within the forsterite field, the melting point of forsterite 1890°C.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phase presented |
|---|---|---|---|---|---|
| 24 | 24 | 52 | 1432 | 10 | Glass |
| | | | 1426 | 10 | Glass + trace crystals |
| 23 | 28 | 49 | 1528 | 10 | Glass + trace crystals |
| 27 | 26 | 47 | 1501 | 15 | Glass + crystals |
| | | | 1509 | 15 | Glass |
| 28 | 24 | 48 | 1460 | 10 | Glass + crystals |
| | | | 1468 | 10 | Glass |
| 30 | 25 | 45 | 1490 | 15 | Glass |
| | | | 1485 | 15 | Glass + crystals |
| 32 | 23 | 45 | 1459 | 15 | Glass |
| | | | 1445 | 20 | Glass + crystals |
| 32 | 25 | 43 | 1498 | 15 | Glass + trace crystals |
| 32 | 26 | 42 | 1506 | 20 | Glass + crystals |
| | | | 1510 | 20 | Glass |

The liquidus-solidus temperature relations have now, as far as possible, been determined over the entire ternary system and they may be represented by a solid model constructed by properly filling in the model shown in fig. 9. A photograph of this solid model is shown in fig. 11. These relations may also be indicated by means of a triangular concentration diagram similar to the one shown in fig. 8, upon which isotherms have been drawn and the temperature of the fixed points given. In figs. 12 and 13 are such diagrams, 12 given in weight percent and 13 in mol percent.

### Discussion of the Fields.

A complete discussion of the wollastonite, of the pseudowollastonite and of the $5CaO.2MgO.6SiO_2$ solid solutions and their respective fields will appear in a subsequent paper. The general conclusions only will be indicated at this time.

*The pseudowollastonite field.*—This field belongs to solid solutions whose compositions form an area bounded by the $CaO.SiO_2$-CaO side line, the $CaO.SiO_2$-diopside line and a line extending from the compositions CaO 44·4, MgO 3·1, $SiO_2$ 52·5, on the $CaO.SiO_2$-diopside line to the composition CaO 46·7, MgO 3·5, $SiO_2$ 49·8, on the $CaO.SiO_2$-$2CaO.MgO.2SiO_2$ line and probably to the composition CaO 50, $SiO_2$ 50 on the side line.

*The wollastonite field.*—The evidence does no more than establish the existence of this tiny field which belongs to the most concentrated solid solution of diopside in wollastonite which decomposes at the highest temperature. This solid solution containing between 3·1 and 3·5 percent MgO or approximately 17 percent of diopside has the highest decomposition temperature, 1340 $\pm 5°$C, the pure wollastonite inverting to pseudowollastonite at 1200°C. The limit of 3·1 to 3·5 percent MgO agrees with the limit of 3·15 MgO (17 percent diopside) found by Allen and White as does the decomposition temperature of 1340°C with their observations.[42]

*The $5CaO.2MgO.6SiO_2$ field.*—This field belongs to a series of solid solutions which are not stable at their melting points and which lie on or near the $5CaO.2MgO.6SiO_2$ composition. The fact that the decomposition temperatures of these and other solid solutions rise sharply as

[42] This Journal, 27, 1, 1909.

the composition $5CaO.2MgO.6SiO_2$ is reached was interpreted as indicating the existence of this compound. Its decomposition temperature is somewhat difficult to determine directly but from the liquidus relations must be $1365 \pm 5°C$, the temperature which corresponds to point 13.

*The diopside ($CaO.MgO.2SiO_2$) solid solution.*—Diopside has previously been shown by several investigators to form no solid solution with silica, forsterite or pseudowollastonite. Similarly it does not form solid solutions with the compound $2CaO.MgO.2SiO_2$ to any great extent. A charge of the composition CaO 26·5, MgO 18·5, $SiO_2$ 55, was found to contain after a 15 hour heat treatment at 1300°C, crystals of $2CaO.MgO.2SiO_2$ in such quantities as to indicate not more than a trace of such solid solutions. However, diopside forms a continuous series of solid solutions with clino-enstatite $MgO.SiO_2$, a thorough discussion of which has been given by Bowen.

*The $CaO.MgO.SiO_2$ (monticellite) solid solutions.*—The temperature relations along the monticellite-periclase boundary line 10, 11, are such as to indicate considerable solid solution between monticellite and forsterite.[43] The limit thus indicated would be about ten percent forsterite, or to the composition CaO 32, MgO 28·75, $SiO_2$ 39·25. Owing to the difficulties encountered here, due to the great readiness with which magnesia crystallizes and the great slowness with which it is resorbed, only a few confirmatory experiments were made. These indicated that the solid solution extends at least to the composition CaO 33, MgO 28, $SiO_2$ 39.

Attempts to prepare pure monticellite did not succeed. Instead of a homogeneous mass of this composition a mixture of crystals of $\alpha 2CaO.SiO_2$ and crystals of a monticellite solid solution was always obtained even though the original charge consisted of a glass in which very minute crystals of magnesia were imbedded. This result may be explained by reference to fig. 14 which is an enlargement of this portion of the diagram given in fig. 8. The arrows indicate the direction of falling temperatures. The maximum C on the line 10, 11, represents the decomposition temperature of the solid solution D and there

[43] The existence of such solutions was previously discovered but the somewhat crude apparatus used in the investigation made the interpretation of the results an uncertain matter. P. Herman, Zeit., d. deutsch Geol. Ges. 58, 39, 1906.

must be a maximum on the line 8, 9, at B although due to the slight temperature gradient we have been unable to detect it. The field B, 9, 11, C is the field of the solid solution D and the field B, 8, 10, C is the field of the solid solutions with compositions on the line DM. The exact liquidus-solidus relations cannot be determined because of the difficulties inherent in the microscopic examination of these solutions. The decomposition temperatures along DM are evidently all lower than the temperature at D but one cannot say if they change gradually from D to M or if they pass through a minimum between D and M. If a minimum is present then the point 10 represents a glass which can coexist with a solid solution of an

FIG. 14.

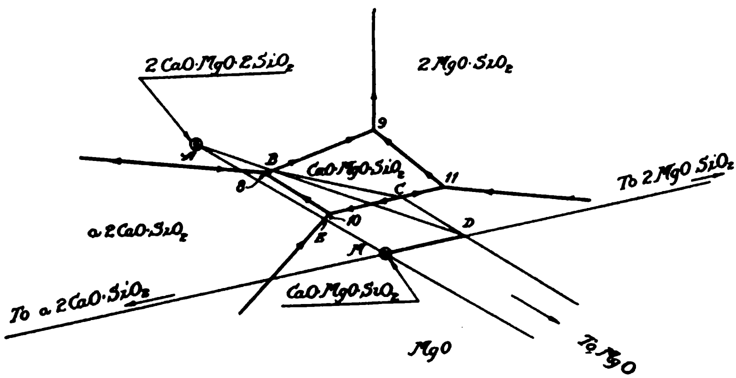



FIG. 14.—An enlargement of that part of the diagram given in fig. 8 which deals with the monticellite solid solutions with some additions designed to aid in the discussion of these solid solutions.

intermediate composition to D and M. If a minimum is not present this may or may not be the case and the pure compound may be stable in the presence of the glass 10. Our inability to prepare the pure compound cannot be reconciled to this latter theoretical possibility and it would therefore appear reasonably certain that the glass 10 corresponds to a solid solution with a composition intermediate with D and M. The crystallization of a glass M of the composition $CaO.MgO.SiO_2$ would be:

1. Liquid.
2. Magnesia and liquid. The liquid composition varies from M to E along ME.
3. Magnesia, $\alpha 2CaO.SiO_2$ and liquid. The liquid composition follows the line E 10 to 10.

4. The magnesia disappears and the charge becomes completely crystalline at 10 to form a mixture of $\alpha 2CaO.SiO_2$ and a solid solution X. The last liquid has a composition represented by the point 10. The solid solution X lies on the line MD between M and D.

Were it possible to make a reaction take place in the solid state in a reasonable time, pure monticellite would be formed when the mixture of $\alpha 2CaO.SiO_2$ and the solid solution X were heated at temperatures below the decomposition temperature of the pure compound.

*Åkermanite.*—Many attempts have been made to explain the composition of the members of the melitite group of minerals (tetragonal in symmetry), and most of the resultant explanations have presupposed the existence of a mineral åkermanite. Vogt[44] assumed the formula of this pure compound to be $4CaO.3SiO_2$ although usually part of the lime was "replaced" by magnesia or a like base. Day and Shepherd[45] were, however, unable to obtain any evidence of the existence of such a compound in their investigation of the lime-silica series of minerals. Later Rankin and Wright[46] noting the similarity between some of the properties ascribed to åkermanite and those of the compound $3CaO.2SiO_2$ (orthorhombic in symmetry) suggested that the latter might be the åkermanite analogue in the binary system. More recently Schaller,[47] recognizing the ternary nature of the melitite group, has stated that the correct formula for this second compound is $8CaO.4MgO.9SiO_2$.

Since the compound $4CaO.3SiO_2$ has never been prepared in the pure state and there is little real evidence of its existence, this formula may be regarded as purely speculative.

The formula $8CaO.4MgO.9SiO_2$ is based on Schaller's interpretation of two analyses[48] of a tetragonal Vesuvian mineral. This interpretation would need but little modification if the formula were written $2CaO.MgO.2SiO_2$, corresponding to the tetragonal ternary compound of this system.

The essential optical properties of the analyzed åkermanite (1) and of the ternary compound (2) are compared as follows:

[44] T. H. L. Vogt, Mineralbildung in Schmelzmassen, 96, 1892.
[45] A. L. Day and E. S. Shepherd, this Journal, 22, 280, 1906.
[46] G. A. Rankin and F. E. Wright, this Journal 39, 1, 1915.
[47] W. T. Schaller, U. S. Geol. Survey, Bull. 610, 1916.
[48] See F. Zambonini, Mineralogia Vesuviana, 255, 1910.

| | $\omega$ | $\epsilon$ |
|---|---|---|
| (1) | 1·6332 | 1·639 |
| (2) | 1·631 | 1·638 |

We have been unable to prepare a compound or solid solution having more nearly the formula 8CaO.4MgO.9$SiO_2$. The compound 2CaO.MgO.2$SiO_2$, as far as we know, forms no appreciable solid solutions.

In this connection attention may be called to the confusion which may arise from the use of such formulas as 4R″O.3$SiO_2$ applied to minerals. For the sake of simplicity let us assume that we have a case in which R″O

Fig. 15.

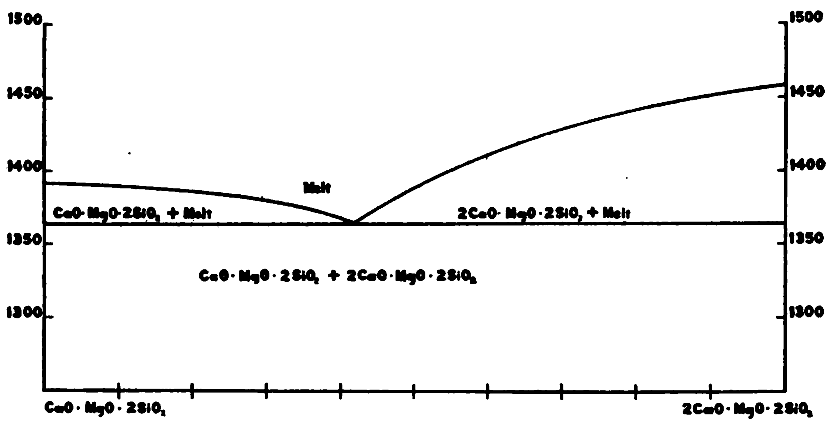



Fig. 15.—The binary system CaO.MgO.2$SiO_2$-2CaOMgO.2$SiO_2$. wt. per cent.

represents but two oxides.[49] As so used R″ may represent any one of three things: either (1) two elements in a definite ternary compound; or (2) two elements in solid solutions containing no ternary compounds, but only component oxides and binary compounds, or binary compounds alone; or (3) two elements in solid solution involving ternary compounds, either alone, or with binary compounds, or with component oxides or with both.

*The tridymite-cristobalite inversion.*

The tridymite-cristobalite transformation is very sluggish even when it takes place through solution. Fenner[50]

[49] Similar statements would apply to minerals containing more than three components, but with additional complications.
[50] This Journal (4), **36**, 331, 1913.

in his investigation of it used a flux of sodium tungstate. We have studied it in melts of our ternary system. We selected a composition, CaO 24, MgO 7, $SiO_2$ 69, which lies within the silica field and melts completely at 1536°C. The tridymite and cristobalite present in the various quenches made could not be separated and analyzed, therefore the only evidence that they are little if any affected by solid solution rests upon determinations of refractive index. The values obtained agree within ± 0·003 with those of purest natural crystals and with Fenner's values for material formed in molten sodium tungstate. Our observations are given below.

Fig. 16.

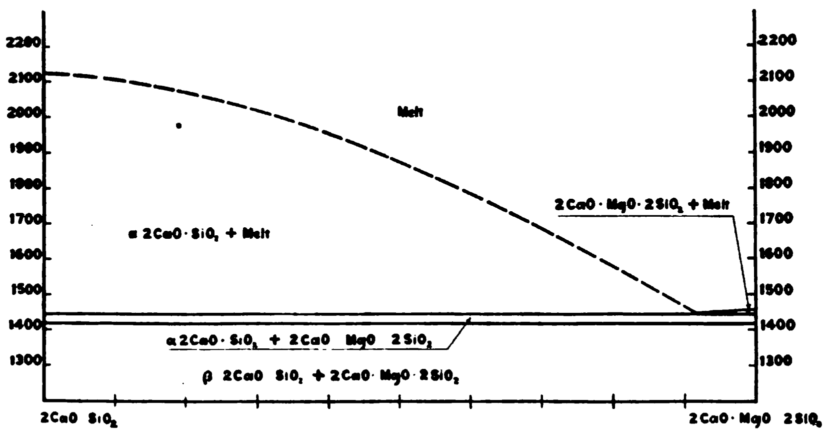



Fig. 16.—The binary system $2CaO.MgO2SiO_2$-$2CaO.SiO_2$. wt. per cent.

1. A charge containing only tridymite plates and glass was prepared by heating the original material which contained cristobalite for 16 hours near 1370°C, the eutectic temperature being 1320°C. Portions of this charge were then given the following treatments.
   - (*a*) Heated 5 hours at approximately 1530°C. The charge then contained much cristobalite.
   - (*b*) Heated 5 hours at 1515°C and then 10 hours during which time the temperature fell to 1500°C. The charge contained cristobalite; no tridymite could be identified.
   - (*c*) Heated 9½ hours at 1496°C. Much tridymite, no cristobalite identified.

FIG. 17.

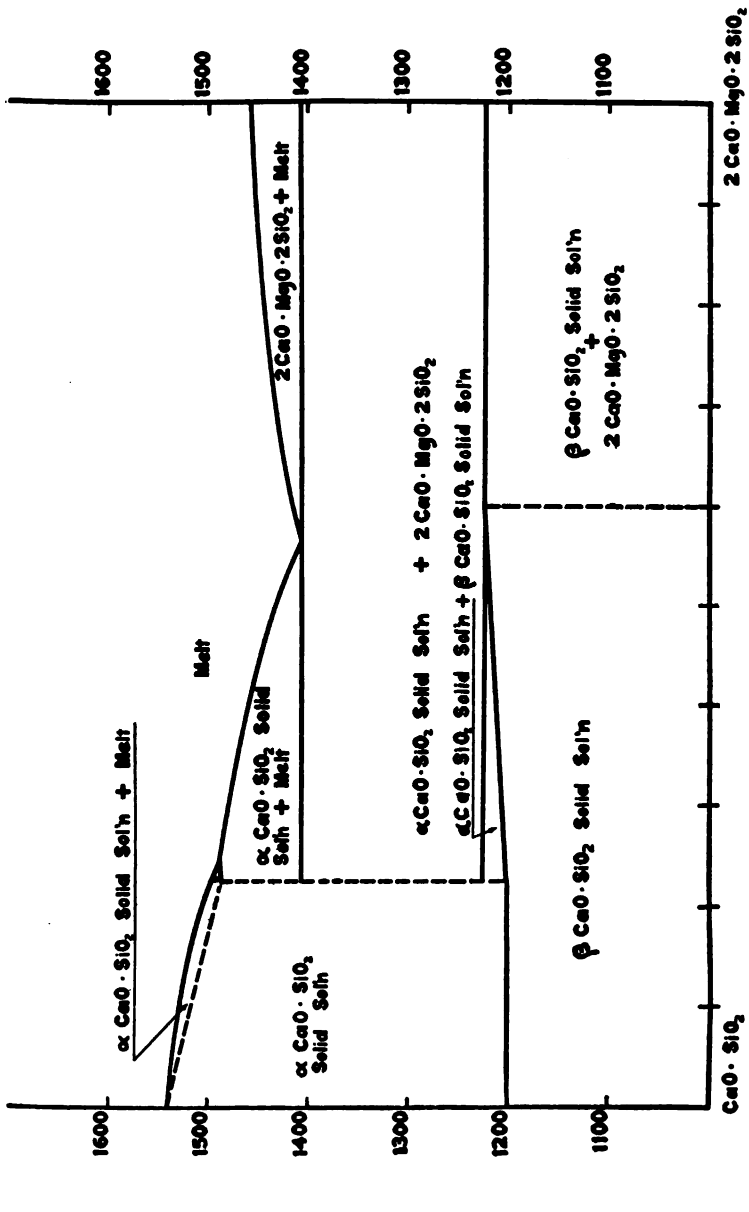



FIG. 17.—The binary system $CaO.SiO_2$-$2CaO.MgO.2SiO_2$, wt. per cent.

2. The charge which contained only tridymite was mixed with some of the original material forming a charge containing both cristobalite and tridymite. This material was treated as follows:
   (*a*) Heated at 1515° for 3 hours. Both tridymite and cristobalite identified.
   (*b*) Heated at 1485° for 3½ hours. Both tridymite and cristobalite present.
   (*c*) Heated for 16 hours, the temperature falling from 1500°C to 1483°C. Little if any change.
3. A charge containing cristobalite + glass — heated all night at 1464°C. No tridymite formed.

These results confirm the observations of both Fenner and Bowen[51] upon the sluggishness of this inversion, and because of this sluggishness it is impossible to fix upon an exact value for the inversion temperature in this system. Our results certainly indicate a value in this silicate system which lies below 1500°C with cristobalite as the stable high-temperature form. Fenner found in the tungstate melts, 1470 ± 10°C. Only slight, if any, solid solution could have been present to affect our measurements or Fenner's, which are in substantial agreement.

### The Binary Systems within the Ternary System.

The presence within the ternary system of so many compounds which melt incongruently and also so many solid solutions, renders the binary systems rather few in number. The systems $CaO.MgO.2SiO_2$—$2CaO.MgO.2SiO_2$ and $2CaO.MgO.2SiO_2$—$2CaO.SiO_2$ are of the simplest type and are given diagrammatically in figures 15 and 16 which were obtained by interpolation from the melting temperatures determined for compositions lying in the fields of these compounds. The system $CaO.SiO_2$—$2CaO.MgO.2SiO_2$ is more complicated including as it does several series of solid solutions. The evidence upon which the purely solidus relations are based will be given in a later paper but for the sake of completeness the general results are included in the diagram given in fig. 17.

[51] This Journal (4), 38, 245, 1914.

In conclusion, thanks are due Dr. N. L. Bowen for his friendly criticisms and Mr. G. A. Rankin for certain preliminary results which he generously placed at our disposal at the commencement of the investigation.

## SUMMARY.

The ternary system lime-magnesia-silica has proved to be the most complicated of the four possible ternary systems which may be constructed from the four oxides, lime, magnesia, alumina, and silica. The crystalline phases which are definite compounds and which appear as primary phases are as follows:

Lime; magnesia; silica (tridymite and cristobalite); $\alpha CaO.SiO_2$ (pseudowollastonite); $3CaO.2SiO_2$; $\alpha$ and $\beta$ $2CaO.SiO_2$; $MgO.SiO_2$ (clino-enstatite); $2MgO.SiO_2$ (forsterite); $CaO.MgO.2SiO_2$ (diopside); $5CaO.2MgO.6SiO_2$ and $2CaO.MgO.2SiO_2$. The melting point of $2CaO.MgO.2SiO_2$ is 1458° ± 5°C and the decomposition temperature of $5CaO.2MgO.6SiO_2$ is 1365° ± 5°C.

In addition to these, crystals representing several solid solutions also appear as primary phases. The solid solutions are:

1. A complete series with clino-enstatite and diopside as end members, generally known as pyroxenes.
2. The pseudowollastonite solid solutions whose compositions form an area bounded by the following lines: (1) the $CaO.SiO_2$-$CaO.MgO.2SiO_2$ line; (2) a line running from the composition CaO, 44·4, MgO 3·1, $SiO_2$ 52·5 on the above-mentioned line across to the composition CaO 46·7, MgO 3·5, $SiO_2$ 49·8 on the $CaO.SiO_2$-$2CaO.MgO.2SiO_2$ line; (3) then either the last-mentioned line back to $CaO.SiO_2$, or, more probably, an approximate continuation of line (2) to about the composition CaO 50, $SiO_2$ 50, on the side line.
3. The wollastonite solid solutions; these extend to about 17 percent diopside or 3·2 percent MgO at the higher temperatures. The most concentrated of these solid solutions along the diopside line (the 17 per cent) decomposes at 1340° ± 5°C, and this solid solution is the only one represented on the liquidus.
4. The $5CaO.2MgO.6SiO_2$ solid solutions. Only a few of these solid solutions which are decomposed at the higher temperatures near the decomposition-temperature

of the pure compound are stable in contact with a suitable liquid.

5. Certain members of the monticellite solid solutions. Monticellite takes up forsterite in solid solution to the extent of about ten per cent and the decomposition temperature of the solutions is thereby raised. Monticellite itself probably decomposes at too low a temperature to ever occur at a primary phase.

The temperature-concentration relations of the liquids which may be in equilibrium with each of these phases have been thoroughly investigated where necessary by means of the quenching method, and the results obtained have been correlated with the existing data on the remainder of the ternary system.

The compounds $5CaO.2MgO.6SiO_2$ and $2CaO.MgO.2SiO_2$ have not been prepared previously. Attempts to prepare a compound of the formula $8CaO.4MgO.9SiO_2$ (Schaller's åkermanite) gave negative results.

The monticellite solid solutions and the compound åkermanite are discussed at length but the wollastonite and the $5CaO.2MgO.6SiO_2$ solid solutions are only briefly mentioned as they will be made the subject of a subsequent paper.

Experiments were made on the tridymite-cristobalite inversion temperature, which was found, for this system, to be below 1500°C, in approximate agreement with Fenner's original value of 1470°; the great sluggishness of the inversion precluded a more exact determination on our part.

Geophysical Laboratory, Carnegie Institution of Washington, Washington, D. C., April, 1919.

ART. VIII.—*Some Notes on Japanese Minerals;* by SHIMMATSU ICHIKAWA.[1]

VIII. *Secondary report on the natural Etchings of Calcite Crystals* (I and II).

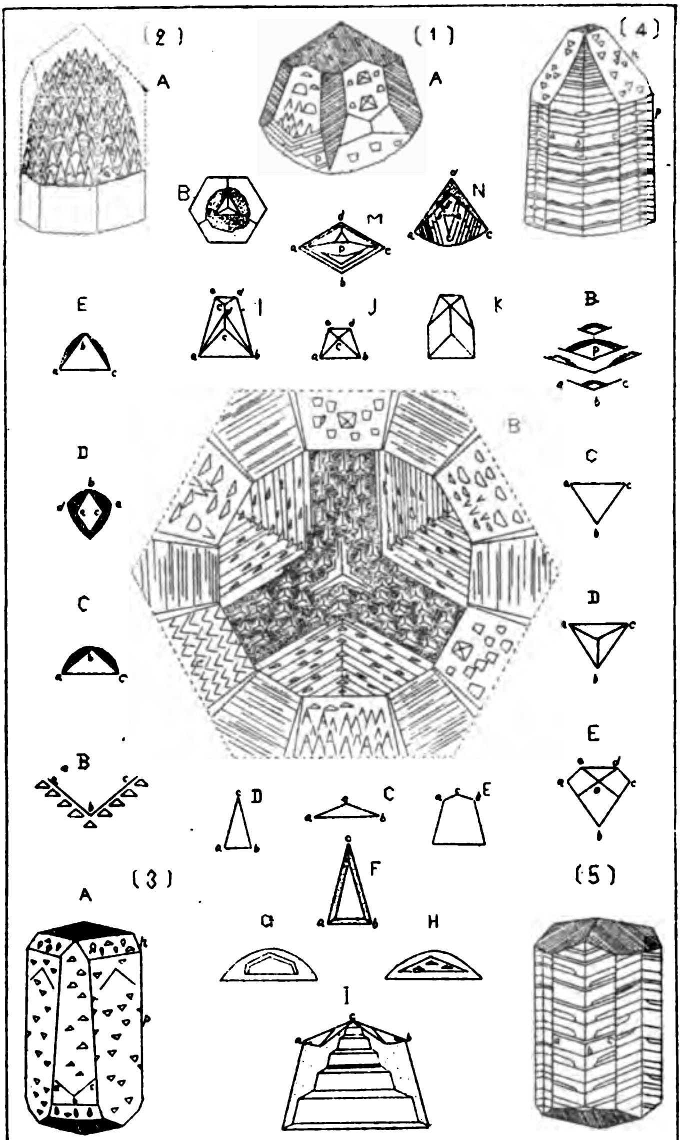
Natural etchings of calcite crystals from Shimoshinjo, Echizen Province, have already been described in this Journal.[2] Since then, I have repeatedly visited this and other calcite localities and collected additional crystals more etched than those before described. These specimens are illustrated in the accompanying pages, 125, 127, I and II. The striations formed by etching can be barely observed by the naked eye and the pits, elevations, etc., can only be investigated minutely under a magnification of 75 to 140 diameters. The locality of the specimens is Shimoshinjo, Echizen.

Fig. 1 (I) shows the etching of a scalenohedral crystal; A is a front view (×5); B, a horizontal projection on the vertical axis of A. C, D, E, etc. show varieties of natural pits on the face *mR*. E is the combination of two pits C and D; F is more etched than D, the three lateral sides sloping down to the base; G, H, I, etc. show a group of the C or C, E type of pits, etc. respectively. C sometimes shows a curved form as in the external part in G and H; the angle *acb* is for C = 140°; D = 30°; E and I = 140°; F = 30°. J, K, L, etc., show varieties of natural pits on the face *mR*. K is a combination of two individuals of the J type pit. The angles for J are: acb = 80°; dce = 110°; for L, acb = 80°; dce = 110°; adb = 60°. M shows a trigonal pyramidal elevation on the face *mRn,* in horizontal projection. The rhombic plane (abcd) with striations is a face of a rhombohedron formed by etching; the trigonal plane on the top has a strong luster and is a new face formed by etching. N shows a face (*p*) of trigonal pyramidal elevation (M), in horizontal position. The angles are: ab′c = 90°; adc = 70°; bca = 30°. The direction of the isosceles triangle (bca) in the figure is opposite to that of acb in D, but the planes of both the triangles are parallel. Rhombic plates (*p*) in A, and trigonal plates (*t*) in B are

[1] For two earlier papers, see this Journal, vol. 42, pp. 111-119, August, 1916; vol. 44, pp. 63-68, July, 1917.

[2] Ibid., vol. 42, pp. 113-115, 1916.

I.




I. Natural etchings of calcite crystals. S. Ichikawa del.

elevations formed by etching; the striations on the faces *mRn*, etc., also are formed by etching, and the striations are parallel to the direction of cleavage.

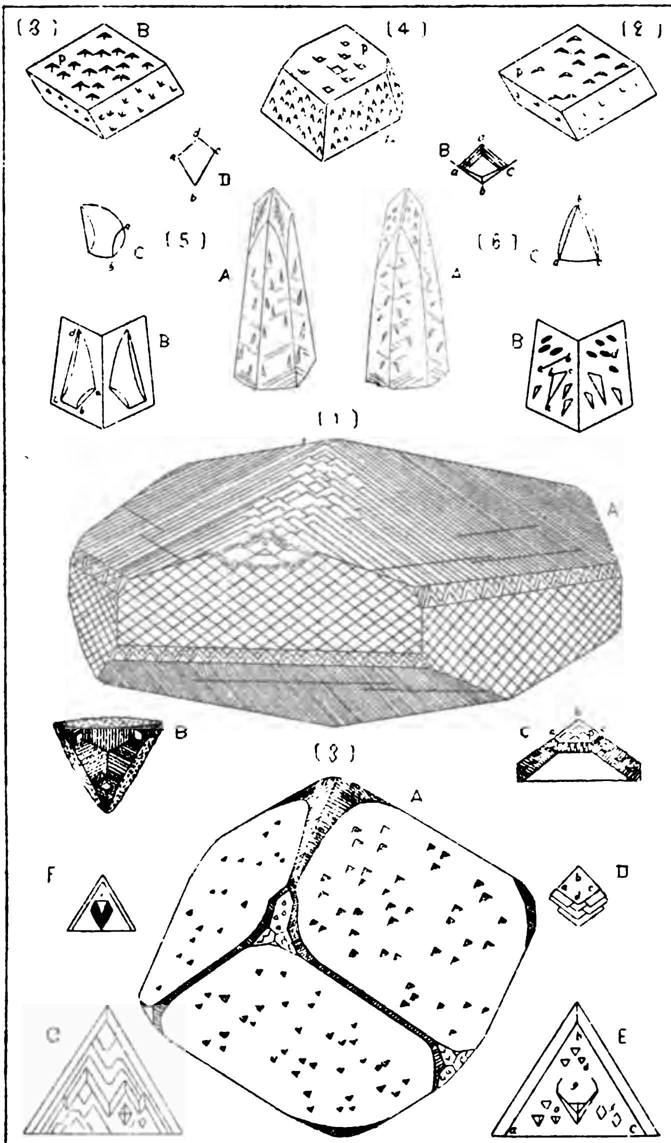
Fig. 2 (A) shows a crystal strongly etched; the pyramid is rounded and has numerous new forms like an acute trigonal pyramid on its surface; this new form is similar to C of figure 4 (this Journal, vol. **42**, pp. 114, 1916), but the former is a front view and the latter is drawn in perspective. B shows the relation between the outline of the top of the new form and the edges of the original crystal in a horizontal projection.

Fig. 3 shows the etching of a prismatic crystal. A is a front view; B shows a V-shaped figure (abc) on the face *mR* and the arrangement of the trigonal pits; C is a trigonal pit on the face *p;* D and E show varieties of natural pits on the face *mR*. The angles are: A, B, C (abc) = 100°; D, E(abc) = 70°; D(dbe) = 100°.

Fig. 4 is a prismatic crystal with *mR*, A is a front view (× 5); B shows striations and pits on the face *mR* deeply etched. The base of the pit is parallel to the cleavage, and the angle abc = 145°. C, D, E, etc. show varieties of natural pits on the face *mR;* the angles are C, D, E(abc) = 75°; E(doe) = 105°; E(bcd) = 100°. Fig. 5 shows etchings in a prismatic crystal with dihexagonal prism ($\infty$ P*n*) (× 5). Striations of AB, BC, etc. on the prism are parallel to the direction of cleavage; abc = 145°.

On the second page of the figures (II), figure 1 shows a short prismatic crystal from a crystalline limestone at Kamiōmushi, Echizen Province. Rhombic plates on the face —½*R* and trigonal plates on the face *mR* are new faces formed by etching. Cross striations on the faces —½*R* and $\infty$ *R* show the direction of cleavage. The crystal is nearly opaque and has a transparent greenish coating, but the face *R* looks almost white being formed by innumerable rhombic etching planes (D). A is a front view (×10); B shows an elevation formed on the face —½*R* in horizontal projection; the three rhombic planes are new faces of a rhombohedron formed by etching. C shows an elevation produced on a trihedral angle (*a* in A) formed by the combination of the faces —½*R* and $\infty$ *R*; D shows a group of rhombic plates formed on the face $\infty$ *R*; E, F, G, etc. show trigonal plates formed on the face *mR* and varieties of natural pits formed

II.



II. Natural etchings of calcite crystals. S. Ichikawa del.

on the new faces; in G a group of lamellated trigonal plates are shown. The angles are: C(abc) = 110°; D(abc) = 90°; D(adc) = 110°; E(abc) = 65°.

It is shown here that the sides of the trigonal plates (E, F, G, etc.) on the face *mR* and those of the natural pits (*d, e, f,* etc.) on the trigonal planes are parallel to the rhombohedral cleavage (see cross-striations in A). The reader must compare the natural pits of *d, e, f,* etc. on E, F, G, etc. with those in *mR* of II; see also this Journal, vol. **42**, pp. 114, 1916. Figure 2 shows a new rhombohedral form formed on $-\frac{1}{2}R$ of figure 1, A and the natural depressions on its faces. Figure 3 shows the etching of a cuboid calcite crystal found in a Tertiary tuff at Maruyama, Echizen. A is a front view (× 10). On the rhombohedral faces trigonal pits are found, and on the scalenohedral faces striations are noted. B shows a cleavage fragment (R) with depressions formed by etching.

Fig. 4 shows the etching of a scalenohedral crystal (with cleavage face) found in the zincblende mine at Nerimata. A is a front view; B shows the natural depressions formed on a cleavage face of A; the angles are: abc = 112°; adc = 100°; compare also figure 1, D (II) and figure 4, B (I). Figure 5 shows the etching of a scalenohedral crystal also from a crystalline limestone at Kamiōmushi. The face *mR* is depressed in the direction of longer diagonal by etching. B shows the relation between the outline of the natural depression and the edges, striation, etc. of the face (*mRn*); the angles are: abc = 110°; bcd = 105°; cda = 30°. The direction of *cb* in the depression is parallel to the striations on the face. C and D also are natural depressions observed on the same face; the angles in D are: abc = 60°; bad = 100°; adc = 100°. The direction of *ab* in D is parallel to that of *ab* in B.

Fig. 6 shows the etching of another scalenohedral crystal from the same locality. B shows the relation between the outline of varieties of the natural pits and edges, striation, etc. of the face *mRn*. The line *ab* in the figure shows a fissure in the direction of cleavage. Long elliptic natural depressions on the face much resemble a part (*ab*) of the natural depressions in figure 5, B. C shows a trigonal pit on the face *mR*: the angle abc = 40°.

The symmetry of the etched figures shown in I and II

corresponds to the rhombohedral type; the resulting form in the etching again is repeated as follows:

*a.* At the beginning of etching, the faces $-\frac{1}{2}R$, $mR$, $\infty R$, $\infty Pn$, etc. form new faces of a rhombohedron (see I, figure 1, A; figure 4, B; figure 5 (abc); also II, figure 1, A, B, etc.) in the direction of striations on their crystal faces, and natural pits on the new rhombohedron much resemble pits on the cleavage face (compare figures 2, 3, 4, etc. in II).

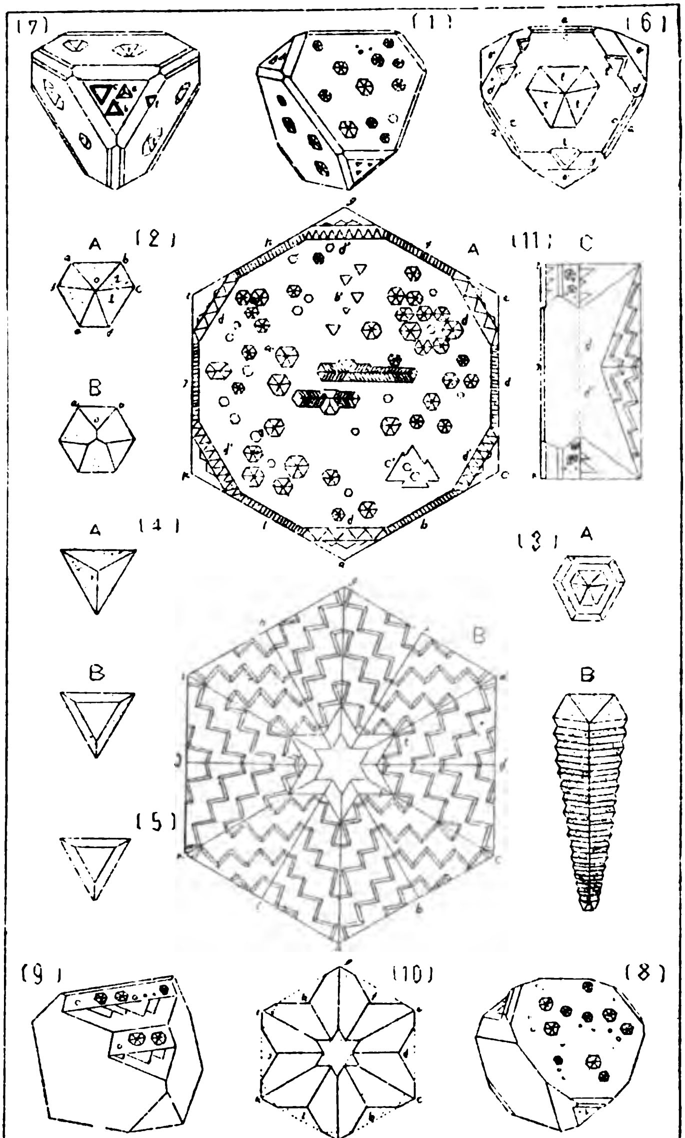
*b.* In the progress of etching, the faces $R$, $mRn$, etc. yield new forms resembling an acute trigonal pyramid (see I, figure 1, M, N, and figure 2, etc.) in the direction of the vertical axis and the position of the lateral axis of the new form also corresponds with the position of the axis of rhombohedron (+ R) in the crystal.

### IX. *Natural pits of Zincblende Crystals* (III).

In 1908 I visited the Kuratani mine in Kaga Province and collected zincblende crystals with natural pits. The results of the study of these natural pits are shown in the accompanying figures (III). The crystals occur in a clay vein, color black; luster brilliant; habit tetrahedral with traces of the dodecahedron $mOm$, etc. They measured 3 to 8 mm. in diameter, penetration twins are often observed and simple crystals are very rare; the natural pits were more often found in the former than the latter. Polysynthetic twins can be barely observed by the naked eye, and the natural pits, striations, etc. can only be investigated under a magnification of 75 to 140 diameters. Figure 1 (III) shows hexagonal pits and trigonal elevation on the tetrahedral faces ($\times$ 8). Figure 2 shows two hexagonal pits on the tetrahedral face; the angles are: aob = 75°; cob = 45°. Figure 3 shows two groups of hexagonal pits. Figure 4 shows two equilateral trigonal pits. Figure 5 shows an equilateral trigonal elevation on the tetrahedral face; the direction of the elevation is opposite to that of the pit.

Fig. 6 shows the relation between the outlines of hexagonal pits and the edges of a tetrahedron (with $o'$, $d$, $a$, and $mOm$, etc.), in a horizontal projection on the trigonal axis. The wall of V-shaped pits ($t'$) on the dodecahedral face is parallel to a large wall ($t$) of hexagonal pits on the tetrahedral face (see figure 11, A). Figure 7 is the

III.



III. Natural pits of Zincblende crystals. S. Ichikawa del.

same as figure 6, but shows both pits and elevations on the face. A and b are trigonal pits; c a trigonal elevation. Figures 8 and 9 show repeated twin on *o*, Figure 10 shows a penetration-twin of two tetrahedral crystals in horizontal projection. Figure 11 shows pits of a penetration twin that is in the same position as figure 10.

A shows a face of the tetrahedron cut to dodecahedron by extension of the dodecahedron accompanied by each individual in the twin, *a′*, hexagonal pit; *b′*, trigonal pit; *c′*, trigonal elevation. The summit angle of the V-shaped pits on the dodecahedral face is 75°, and their walls are parallel to one of the alternate large walls (*t*) of the hexagonal pits on the dodecahedral plane. Striations on the sides of *b, d, f, h, j, l,* etc. are parallel to one edge of the V-shaped pits adjoining the dodecahedron; therefore, it is proved that V-shaped pits and striations on alternate external sides of the dodecahedral plane are formed by development of a part of hexagonal pits on internal surface of the plane. B, is a reversed form of figure A (compare figure 10). C shows the union of two dodecahedrons in a lateral face (i, j, k) of figure B, in horizontal position.

The above study shows that hexagonal pits are only observed on the face of the plus tetrahedron, and trigonal pits, elevations, etc. are found on the faces of both tetrahedrons (refer to figures 7 and 11, A).

Kitashinjo-mura. Imatate-gun, Fukui-ken,
Japan, May, 1918.

ART. IX.—*Additional Facts Relating to the Granite Bowlders of Southeastern Kansas;* by W. H. TWENHOFEL.

Since the writer described the granite bowlders which occur near Rose, Woodson County, Kansas,[1] some additional facts have been discovered. These are given in this article.

At the time the bowlders were first described, different hypotheses relating to their origin were considered and the one which ascribed their presence to the agency of floating ice was accepted as best harmonizing with the observed facts. The most reasonable source for the bowlders was suggested as being to the southeast.

Subsequently Darton suggested[2] that the parent rock is probably to be found on the northern end of the buried mountain ridge of Central Kansas, since there its summit comes within 600 feet of the surface. At the time the bowlders were discovered very little was known of this buried ridge. Granite had been reached in several wells in Central Kansas and fragments of this granite had been brought to the surface. Some of these had been examined by the writer and found to be altogether unlike the rock of the Rose bowlders and it was considered quite improbable that any connection existed between them. Later, descriptions of granitic rocks from a number of other wells were published[3] and recently, through the kindness of Professor C. E. Decker of the University of Oklahoma, an opportunity was given of examining several small pieces of granite which came from the Kaufman well, near Elmdale, Chase County, Kansas. In no respects do any of these fragments resemble the rock of the Rose bowlders, and the published descriptions do not suggest that rock similar to that of the Rose bowlders has been found. Facts of this nature, however, mean little. There may be, and probably are, scores of varieties of rock in this old ridge, and it is absolutely certain that only a few of them have been reached by the drill, so that the ridge must be considered as a possible source

[1] This Journal, 43, 363-380, 1917.
[2] Darton, N. H., U. S. Geol. Surv., Bull. 691-A, 5, 1918.
[3] Moore, R. C., and Haynes, W. P., Kansas Univ. Geol. Surv., Bull. 3, 140-169, 1917. Complete references are given in this work.

for the bowlders, if they were really transported as the writer has suggested.

One of the hypotheses considered when the bowlders were discovered, and one that was subsequently suggested by others with whom the writer discussed the problem, is that there may be a dike in the Pennsylvanian sediments at this place, and it was pointed out in the original article that the linear distribution of the bowlders is in harmony with such an interpretation. The coarse texture of the granite composing the bowlders and the absence of metamorphism of the adjacent sediments led, however, to the rejection of the hypothesis. Recently a well has been drilled about a quarter of a mile almost due south of the largest accumulation of the bowlders, and its record, as given below, throws a little light on the possibility of a dike at this place.

| | | |
|---|---|---|
| Soil | 2′ | 2′ |
| Clay plus lime | 33 | 35 |
| Limestone | 40 | 75 |
| Shale | 75 | 150 |
| Limestone | 20 | 170 |
| Shale | 5 | 175 |
| Limestone and shale | 10 | 185 |
| Shale | 35 | 220 |
| Limestone | 5 | 225 |
| Shale | 25 | 250 |
| Limestone | 55 | 305 |
| Shale | 40 | 345 |
| Limestone | 10 | 355 |
| Limestone and shale | 20 | 375 |
| Limestone | 25 | 400 |
| Sandstone | 10 | 410 |
| Red shale | 30 | 440 |
| Red limestone | 5 | 445 |
| Sandstone and red shale | 10 | 455 |
| Black shale | 5 | 460 |
| Limestone | 5 | 465 |
| Shale | 10 | 475 |
| Limestone | 85 | 560 |
| Shale | 80 | 640 |
| Limestone | 20 | 660 |
| Red shale | 15 | 675 |
| Limestone | 60 | 735 |
| Red sandstone | 35 | 770 |
| Sandstone and shale | 20 | 790 |
| Limestone | 15 | 805 |

| | | |
|---|---|---|
| Shale | 10′ | 815′ |
| Limestone | 10 | 825 |
| Limestone and shale | 10 | 835 |
| Limestone | 10 | 845 |
| Blue shale | 20 | 865 |
| Limestone and shale | 25 | 890 |
| Shale | 5 | 895 |
| Limestone | 5 | 900 |
| Sandstone and shale | 10 | 910 |
| Dark shale | 145 | 1055 |
| Light shale with gas | 15 | 1070 |
| Dark shale | 30 | 1100 |
| Sandstone | 25 | 1125 |
| Shale | 150 | 1275 |
| Limestone | 6 | 1281 |

Three other wells have been drilled about a quarter of a mile southeast of the place where the bowlders are most abundant and one about a half a mile southeast. Three of the wells are about an eighth of a mile from the most eastern occurrence of the bowlders. The writer has not seen the logs of these wells, but if granite were present in any one of them it has not been made known.

The information from these wells weakens the hypothesis that the granite bowlders may have been derived from a dike which lies directly beneath. The evidence, however, is not conclusive, since none of them is sufficiently close to have penetrated a dike if it were in any degree vertical in position.

Powers has suggested that the bowlders have perhaps been derived from a local granite elevation which "might have been undergoing erosion somewhere in the vicinity of Woodson County during the deposition of the LeRoy (*Weston*) shales."[4] When the bowlders were first discovered, the country was quite thoroughly gone over by the writer and others who made the search in his interest and this work has been more or less continued to the present time. At no other place in this vicinity has a single trace of granite been discovered. Wells have been drilled all around the region—the logs of many of these have been examined by the writer—and in none of them is granite known to have been discovered. Such a granite elevation, however, may be present, but, if so, erosion has probably not yet uncovered its summit.

[4] Powers, Sidney; this Journal, 49, 146-150, 1917.

Furthermore, it can hardly be close at hand; but must lie to the westward beneath the cover of higher beds.

The new facts slightly strengthen the hypothesis that the bowlders reached their present position from floating ice. If so carried, their place of origin is as uncertain as before. It may be that Powers is correct and that they were derived from close by; but if so, ice is the only agent that could have carried them. Perhaps they came from the northwest—northern Kansas or southern Nebraska, where the buried granite ridge rises highest; but again floating ice must be called upon to bring about the transportation, and such a source indicates that large accumulations were possible at no great distance above sea-level, which in turn indicates a very cold climate for Kansas during the deposition of the Weston (LeRoy) shales. Until, however, granite like that of the Rose bowlders has been found by the drill at a stratigraphic elevation equivalent to that of the Weston shales (stratigraphic horizon is not meant), such a source must be considered fully as hypothetical as any other.

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# Art. X.—*The Coral-Reef Zone During and After the Glacial Period*; by Reginald A. Daly.



## *Introduction.*

A full understanding of the living coral reefs would mean the conquest of a problem which still demands a huge increase in our knowledge of the principles and facts of oceanography, dynamical geology, and historical geology. Hence this particular problem is a stimulus to further field investigations of most diverse character and of profound importance. Examples are: the quantitative study of wave abrasion, current abrasion, shelf-building, organic deposits, bottom growths, and the physical conditions of life for many marine species of animals and plants; the origin and initial dates of continental shelves, of the islands composed of continental rocks, and of deep-sea volcanic islands and shoals; the quantitative study of subaerial erosion in the tropics; the evolution of marine species; the geological history of climate in the tropics. This many-sided character is well illustrated in the superb Murray Island volume recently published by the Carnegie Institution of Washington, under the direction of Dr. A. G. Mayer.

On the other hand, final success in the attack would deeply affect the outlook for answers to such questions as those relating to: the stability of the earth's crust; "land bridges" and the dispersal of organisms; the origin of the ocean basins; interpretation of ancient limestones and dolomites; shore-line development; the processes of sedimentation in general.

The coral-reef problem now specially needs the attention of geologists, the zoologists having largely furnished their share of the required data. Unfortunately, few geologists have had the opportunity to study reefs in the field or to absorb the information embodied in modern ocean charts and the facts recently acquired by the oceanographers. The geologist's task is, moreover, one of peculiar difficulty. His main endeavor should be to picture the coral-reef areas through their long past; yet much of the record is hidden beneath the sea. His reconstruction of past geography depends on the wise application of his knowledge of present conditions and processes; yet present conditions and processes themselves are to a greater or less extent inherited and therefore only to be thoroughly understood by sound inference. Here, as elsewhere in geology, progress is directly proportional to the advance of properly controlled speculation.

Much of the voluminous literature on the coral-reef problem has little value because authors have not insistently done their utmost to imagine the tropical geography at stages preceding the present, that is, to think geologically. Or, if they have made the attempt, some authors have nevertheless too literally applied the uniformitarian principle. For example, it has been assumed that reef corals and associated organisms have thriven for an indefinitely long time as they do now; or that general sea-level has been essentially constant for a large part of geological time; or that the tropical climate has been nearly constant during the Cenozoic era. Of course no one can yet reconstruct adequately the Paleozoic, Mesozoic, or even Tertiary physiography of the tropical belt, though certain elements are becoming clearer. The attempt to visualize conditions obtaining in the (Pleistocene) Glacial period, particularly with respect to the development of coral reefs, is more hopeful. The following paper sketches the conditions, as inferred with more or less probability, from ascertained facts. It is also intended to supplement a detailed discussion already (1915) published.[1] A new statement seems warranted, partly because the writer's views have not been thoroughly understood, and partly because some aspects

[1] The Glacial-control Theory of Coral Reefs, Proc. Amer. Acad. of Arts and Sciences, vol. 51, pp. 157-251, 1915. See also, this Journal, vol. 30, pp. 297-308, 1910.

of the subject have not been hitherto emphasized. The chief novelty is the conclusion that the smothering (killing) of corals and other reef organisms by stirred sediment must have been specially extensive during the Glacial period—with an important consequence to the theory of the living reefs. Another enlargement of the subject is found in the effort to describe factors connected with the interglacial stages of the Pleistocene period. For the sake of brevity and clearness the writer has adopted a certain positiveness of statement, which is not accompanied by full discussion of many points in the history of the tropical belt.

*Duration and Subdivisions of the Glacial Period.*

The Glacial period was multiple. Its stages, as recognized in North America, are given by Chamberlin and Salisbury:[2]

First glaciation—Sub-Aftonian or Jerseyan (preceded by the Pliocene period).
First interglacial interval.
Second glaciation—Kansan.
Second interglacial interval.
Third glaciation—Illinoian.
Third interglacial interval.
Fourth glaciation—Iowan.
Fourth interglacial interval.
Fifth glaciation—Earlier Wisconsin.
Fifth interglacial interval.
Sixth glaciation—Later Wisconsin.
Post-Wisconsin deglaciation (followed by the Recent period).

"These stages were by no means equal, the earlier being markedly longer than the later. There was something like a geometrical gradation from the earliest and longest to the latest and shortest." These authors place the climax of the Kansan from 300,000 to 1,020,000 years ago; the climax of the Sub-Aftonian was much further back still. Barrell has estimated the total length of the Glacial period as from 1,000,000 to 1,500,000 years.[3]

The total length of the Glacial period in Europe was estimated by Penck at from 500,000 to 1,000,000 years,

[2] T. C. Chamberlin and R. D. Salisbury, Geology, New York, vol. 3, p. 383, 1906.
[3] J. Barrell, Bull. Geol. Soc. Amer., vol. 28, p. 884, 1917.

and by Pilgrim at 1,320,000 years.[4] Pilgrim's assignment of time for the European events of the period is as follows:

| | | |
|---|---|---|
| Günz (earliest) glaciation | 300,000 | years |
| Interglacial interval | 80,000 | " |
| Mindel glaciation | 170,000 | " |
| Interglacial interval | 190,000 | " |
| Riss glaciation | 230,000 | " |
| Interglacial interval | 130,000 | " |
| Würm glaciation | 190,000 | " |
| Post-Würm | 30,000 | " |
| Total | 1,320,000 | " |

Without unduly stressing any of these figures, the experts are generally agreed as to the considerable length of each named subdivision of the Glacial period.

*Shores and Shoals at the Beginning of the Glacial Period.*

From what is known of tropical geology one may fairly consider the early-Pleistocene topography of the coral-reef zone to have been, in the large, of the same quality as the existing topography. The continental shore-lines were not far from their present positions. The larger islands, such as Madagascar, Borneo, Sumatra, Viti Levu, etc. as well as numerous smaller islands, volcanic and other, already existed in their approximate forms. Many shores had been established, through subsidence, elevation, or volcanism, not long before the Pleistocene, and had been comparatively little affected by marine erosion. Others had been established, subject to minor changes, at earlier times, so that broad detrital shelves passing into wave-cut benches, probably narrower than the purely detrital shelves, were already fronting the coasts of Australia, Malaysia, New Guinea, Fiji, etc. Local subsidence of islands and continental borders had caused many embayments by the drowning of valleys.

The sinking of the non-volcanic islands was connected with warpings and faulting of the earth's crust. As indicated in the 1915 paper (page 233), sinking of volcanic

[4] A. Penck, Zs. für Ethnologie, Berlin, 1908, p. 402; L. Pilgrim, Jahreshefte des Vereins für vaterländische Naturkunde in Württemberg, pp. 26-117, 1904.

islands had been occasioned: partly because of the removal of subcrustal lava to the earth's surface, entailing local collapse of the crust; partly because of the compacting of ash, agglomerate, and porous lavas, now deeply buried and therefore strongly compressed by the younger masses which were erupted during the growth of each high cone.[5]

Subsidence due to any of the causes mentioned was local and took place at different times.

Conversely, local uplifts at different times had produced coastal plains, elevated beaches and sea-cliffs, and probably elevated reefs of the fringing type.

Out to sea there must have been many banks of highly varied history. Some of them represented ancient islands—volcanic or otherwise constituted—old enough to have been completely truncated by waves and currents before protecting reef-societies of corals and algae had yet been evolved. Other, younger islands had been similarly truncated, more or less completely, because of the failure of the coral societies to get foothold in their shallows, for reasons which still keep many tropical shores reefless.

One of these reasons needs particular attention. The cone of an explosive volcano, during the upbuilding of its ash-beds into and just above the level of energetic wave-action, is subject to prolonged truncation by the waves. Between explosions the loose materials are levelled, with a tendency to produce a broadening bank covered by 20 to 40 fathoms (36 m. to 73 m.) of water. Judging from the time required to build up cones like Vesuvius, such contemporaneous truncation might form a tolerably wide detrital bank. After later eruptions have succeeded in establishing a stable island, the shelf is further broadened by the addition of land detritus and of organic débris. With extinction of the volcano and with sufficient broadening of the shelf, the mass may finally become the site of a stable reef. Totoya of the Fiji group, with its young cone and wide crater surrounded by a rather wide shelf. seems to be a modern example; many similar cases might be cited. In any case there can be no question as to the contemporaneous trun-

[5] The hypothesis of purely isostatic subsidence seems to be weak on the quantitative side; Barrell doubts the sensitiveness of the earth's crust to loads no greater than the average submarine volcano. (J. Barrell, Jour. Geol., vol. 22, pp. 28-48, 1914.)

cation of certain ash-cones raised to the sea surface during the nineteenth century; nor as to the unlikelihood of reef protection for an ash-cone island in the open ocean, for a coral plantation would there be specially subject to killing by sediment.

Many other pre-Glacial islands must have been truncated or strongly benched because their surrounding waters were too muddy or sandy for coral growth.[6] This is now the case with a goodly number of islands in the Eastern Archipelago.

### *Coral Reefs at the Beginning of the Glacial Period.*

The paleontological record suggests that the late-Tertiary was a time for reef growth probably as vigorous as now, though perhaps far less extensive. The proper degree of association of coral species with each other and with algae, etc. seems to have been evolved already by the beginning of the Cenozoic era, if not earlier. Reef structures competent to resist the waves were thus possible, if the temperature and other physical conditions were right. We may assume that some of the late-Pliocene shores were fringed with reefs. How long those shores had been so protected against wave attack is uncertain, inasmuch as, during the long Tertiary, there may have been periods when the tropical seas were either too warm or too cool for reef growth. If the conditions of the early Pleistocene were the same as now, most shores were reef-free, for at present about two-thirds of the coast lines of continents and larger islands in the warm, tropical ocean fail to show well-developed reefs.[7] Moreover, if a similar ratio of reef-free coasts characterized the Tertiary period generally, wave abrasion could have already produced very extensive shoals at the beginning of the Glacial period.

Tertiary fringing reefs would have been specially developed on the capes or spur-ends between pairs of drowned valleys occurring along shores of subsidence; herein is a partial explanation of the uncliffed forms of many such spur-ends at the present time.

On the other hand, great abundance of atolls or barrier

[6] Sea-cliffs, the proofs of ancient benching, would have faded out, if, since their cutting, their respective shores have been long protected by reefs.

[7] Roughly 65,000 kilometers out of about 100,000 kilometers, measured on L. Joubin's map of the coral reefs of the world.

reefs cannot be *à priori* assumed for the beginning of the Glacial period. It is becoming increasingly clear that each atoll or barrier owes its origin to a positive (upward) shift of sea-level with respect to the foundation of that reef. We know of no strong, general, positive movement of sea-level during the Tertiary, though small shifts of level are practically inevitable in a geological era featured by important deformation of the earth's crust. Local subsidence of the sea-bottom developed barrier reef or atoll, if the subsidence were slow enough and all other conditions were favorable. Very little is known as to the rates of crustal sinking; this and other difficulties stand in the way of inferring the late-Tertiary development of numerous atolls and barrier reefs because of subsidence. Since the existing barriers and atolls can be well explained by a Recent general rise of sea-level, logic forbids us to consider their present abundance as indicating equal abundance at the dawn of the Pleistocene. To make that an axiom would be to "beg the question" concerning the validity of the Glacial-control theory of reefs.

Nor is it likely that many barriers and atolls would have been planted on the stable, late-Tertiary shelves and detached banks. At the edges of these flats, the water averaged probably about 40 fathoms (73 m.) in depth; for long distances inwards the average depths were greater than 20 fathoms, or the lowest limit where reef corals can thrive sufficiently to begin a permanent reef. Farther inshore, where the depths on the shelves were less than 20 fathoms, the rooting of corals must have been largely or wholly prevented through the smothering action of shelf muds and sands stirred up by major storms. The same influence tended to injure even the fringing reefs periodically, so that they had not been permitted to grow to very great widths on the Tertiary shelves.[8]

Tertiary coralliferous limestones are visible today because of uplift, but not one, to the writer's knowledge, has been proved to represent an atoll or barrier reef.[9]

[8] The rate of upgrowth of corals, as deduced from observation on growing specimens, is relatively rapid. The rate of reef outgrowth, depending on the preliminary formation of talus in water 40 to 1,000 or more fathoms in depth, is presumably very much slower, and also merits specific study.

[9] Looseness of thought is inevitable without clear understanding of terms employed. Unfortunately the standard dictionaries do not agree on the definition of either "reef" or "coral reef." Probably a universally

The late-Pliocene reefs are thus considered to have been almost wholly of the fringing type. The younger fringes were narrow because of their youth. The older fringes were probably broader, but their widening had been kept comparatively slow, both by the narrowness of many shelves and because of periodic smothering of reef organisms by shelf sediment.

### *Conditions During the Glacial Period.*

The physiographic influences exerted on the coral-reef zone during every glacial and interglacial stage can not be described in detail. From the facts and probabilities in hand only most general deductions are possible.

That some chilling of the coral seas took place with the onset of each glaciation appears reasonable. A cooling of the present sea by 5° C. would seriously affect the vigor of reef growth. This point has been elaborated in the 1915 paper. Setchell, the leading expert on the temperature relations of the marine algae, holds that the tropical algæ, including the large genus *Lithothamnion*, are highly stenothermic, so that a general chilling of 5° in the tropical ocean might adversely affect the growth or reproduction of *Lithothamnion*.[10] Since Lithothamnia are now reputed to be at least as important as corals

acceptable definition of "coral reef" can not now be framed. However, the structures referred to under that name by Darwin and later students of the reef problem, have typically two features in common: an essential proportion of reef corals in each ridge-like mass, and competence of the structure to resist wave abrasion. Mere abundance of corals is not of itself a sufficient criterion, as Darwin long ago stated (Coral Reefs, chap. 4, section 1). On the other hand, ability to withstand the breakers is absolutely necessary to the typical, sea-level reef. In order, then, to prove that an uplifted coralliferous limestone represents an ancient reef in the Darwinian sense, the former presence of a defensive rim of growing corals and other cooperative organisms must be demonstrated. On account of erosion, here relatively speedy, proof of a former rim may be difficult or impossible. Hence the observer must often remain in doubt as to whether he is dealing with a calcareous sea-level deposit formerly guarded by thriving corals or with a reefless bank, shallow enough to permit the growth of reef corals, which, however, were nowhere assembled after the fashion of a true reef.

Lacking the protective rampart, many shores may thus have undergone prolonged abrasion by waves, although on the shelves offshore, reef corals were growing. On the flat floor of a sinking geosynclinal, coralliferous limestones may accumulate to indefinite thickness without the formation of any reef in the ordinary meaning of that term. A coral patch is not a reef in Darwin's sense; isolated corals or even lenses of corals in elevated limestone are not proofs of former reefs. Failure to observe this has led to some serious errors in reasoning and argument.

[10] W. A. Setchell, personal communication, and Annals, Missouri Botanical Garden, vol. 2, pp. 287-305, 1915.

in giving strength to the normal reef, the weakening of Pleistocene reef-growth seems the more probable. How extensively were the coral seas affected? In what concerns the preparation of platforms for the existing reefs, the complete answer to this question would be more vital if there were not another efficient cause for the wholesale inhibition of reef growth during Pleistocene glaciation—a cause soon to be noted.

The abstraction of water to form the ice-caps, together with gravitative attraction exerted by those masses, lowered the sea-level within the tropics. The amount of the lowering was not equal for the different glacial stages and, of course, varied from minimum (zero?) to minimum (zero?) through a maximum, in each stage. The lowering, like each succeeding rise, was slow—in each case doubtless taking some thousands of years. The greatest lowering of sea-level during the Glacial period has been estimated at from 60 to 70 meters (33 to 38 fathoms). Several important effects should be observed.

(1) Before the first shift of level, the water on the shelf facing a fringing reef was normally so deep that the life of the reef was threatened through smothering by shelf sediment only at the rare intervals of exceptional storms. During and after the lowering of sea-level, the shelf water was withdrawn from the inner part of each shelf and was shallowed ten to forty or more meters on the outer part. The stirring of shelf muds and sands must have been much stimulated. By reason of such turbidity of the shelf water, if for no other reason, the fringing reefs would not be continued as living ramparts, outward and downward, as the sea-level fell. Likewise, coral larvae, if present, could not successfully colonize the shallowing shelf because of smothering. In other words, *the shift of sea-level, of itself alone, entailed a rarely equalled destruction of corals and probably encrusting Lithothamnia as well.*[11] The combination of oceanic chilling and smothering by sediment could hardly fail to reduce coral life on most shores to a very low state, if not to extinguish it altogether.

(2) If protection by vigorous reefs were thus removed, each new coastal plain must have been nipped by the waves and the shore-line pushed landwards. However,

[11] In general, have downward, eustatic movements of sea-level, involving turbidity of shore waters, been influential in the extinction of some coastal species at intervals of geological time?

the waves expended much of their energy offshore, on the shelving flat, which acted as a somewhat prolonged defence against rapid abrasion of the land. For a considerable time both the fringing reef and the underlying bed-rock would be left nearly untouched by the waves when these were beating at lowest sea-level. Farther out to sea wind-driven ocean currents were scouring, attempting to reduce the outer part of the shelf once more to "current base" (usually at about 40 fathoms or 75 meters). The resulting steepening of the bottom gradient ultimately increased the striking power of the shore breakers, and hence accelerated the benching of the coastal-plain sediments. The bluffs of dead fringing-reef would be attacked in their turn, and finally the waves would discover the hard, volcanic or other, rocks beneath the reef. The cliffing of these more resistant rocks must have been very slow. It is probable that the retrogression of the cliffs cut in massive lavas by the waves of the first glacial stage was normally no more than a few hundred meters. If so, very few of these cliffs could now be seen above sea-level.

(3) A third result of the lowering of sea-level must have been the deepening of valleys on the land. The bays due to drowning of valleys in pre-Glacial time were more or less filled with inorganic detritus or weak calcareous deposits. In such materials the streams would speedily bring their channels close to the new base-level, and subsequent widening of the young valleys would be comparatively rapid. Moreover, the fillings of the old drowned-valley bays in open-ocean islands would be attacked by the ocean waves. Hence there would be a tendency toward the removal of the old valley-filling at the pre-Glacial sea-level and for some distance below it. If enough time for the erosion were available, this tendency may have gone to the limit in some cases. The return of the sea to its pre-Glacial level would give such a valley an embayed termination very similar to the original bay, so far as the ground-plan is concerned.

Doubtless much more numerous are the instances where narrow bays were formed by the Recent drowning of valleys which had never been drowned in pre-Glacial time.

In general, the deductions just mentioned apply in principle to the different glacial stages, but probably new

factors were introduced with the first interglacial period; to a brief consideration of these we may now turn.

It is obvious that warming of air and ocean began immediately after, or soon after, the glacial maximum, that is, during a time of lowered sea-level. The conditions of reef growth were established by a bettered temperature and also by the incipient rise of sea-level through melting of the ice. A slight deepening of water on the new shelves and benches decreased the turbidity, which had already been somewhat diminished through gradation of the shelves during the first glacial stage. Hence, well before the end of that stage, corals were able to colonize the outer edges of the shelves, where, on account of "mud-control" (see the 1915 paper), barrier reefs might be expected to develop with special success. In a similar way the outer edges of detached banks would be early colonized, giving atoll reefs.

Whatever flaws there may be in the reasoning so far, one is probably justified in assuming the development of barrier, atoll, and fringing reefs during the first interglacial stage; and also in assuming the usual, partial filling of lagoons with detritus, coral heads, algal growths, plankton remains, etc.[12]

During the second glacial stage the corals may have been injured or killed by oceanic chilling. If so, the reefs and lagoon deposits of the first interglacial stage may have been cut away by the waves at the new sea-level. Even if the corals were uninjured by chilling, they would not necessarily continue to grow on the seaward faces of the young atoll and barrier reefs. Judging from present types, the seaward slopes of the emerged Pleistocene reef were too steep or too sandy to permit coral growth which would be rapid enough to prevent breaching of the reef by the surf. If the reef were

[12] In the writer's 1915 paper (page 180) it was stated that "the sea was actively attacking the islands and continental coasts throughout nearly the *whole* Glacial period. The reef-building corals were largely killed off long before the ice-caps of the first Glacial stage reached their full size. The succeeding Interglacial stage may have witnessed a partial re-establishment of reefs in the open ocean, but, if so, such reefs must have been relatively feeble and short-lived defenders of the islands. Similar reasoning applies to the other recognized stages of the Glacial period. Hence, though sea-level swung down and up several times, lively wave abrasion must have been almost continuous." Further consideration, stimulated by Davis's criticism, has led the writer now to lay more stress on the likelihood of vigorous reef growth during one or more of the interglacial stages. Thus, the degree of continuity for the Pleistocene abrasion seems to be somewhat overstated in the passage quoted.

once breached, the waves and currents would begin to attack the wide mud and "sand" deposits of the lagoon. The resulting turbidity of the water overlying the outer slopes would there injure the chances for successful reef growth. In addition, the outer face of the reef would be subject to invasions of sediment which was eroded by rains falling on the emerged parts of the lagoon deposit, or stirred up by lagoon waves, and finally washed out of the now shallow lagoon through original scour-channels crossing the reef. Hence, here also, smothering by sediment was liable to inhibit coral growth more or less perfectly, even if oceanic chilling did not.

If fringing and barrier reef growth ruled in each interglacial stage, the waves of each glacial stage had much work to do before they could strongly cliff the rocks of the original, pre-Glacial land. Possibly cores of pre-Wisconsin atoll and barrier reefs still persist on some banks, while other banks, thoroughly abraded during the Wisconsin stage, bear only post-Wisconsin reefs. Existing lagoons would correspondingly vary in depth. However, the general similarity of pattern in the atoll and barrier formations of the Pacific and Indian oceans appears to demand that the open-ocean shelves were extensively abraded during a late glacial stage as well as during the first glacial stage.

The last rise of sea-level and the beginning of the melting of the Late Wisconsin ice-sheet were nearly contemporaneous and probably occurred 20,000 to 50,000 years ago. Then began the atoll and barrier reefs which are living because they were able to keep pace with the rising water-level. Some banks were, however, colonized too late or not adequately and have remained reefless to this day. Others, for special reasons, bear reefs of relatively weak or intermittent growth; these reefs are still not able to lift their crests to sea-level and remain "drowned" at depths of ten to twenty meters (roughly five to ten fathoms), for that is the range of depths where the great waves are notably destructive.

Some reefs, originally fringing, followed up the rising water-level, making barriers backed by narrow lagoons. Other fringing reefs have been planted since sea-level reached its present position. Growing outward into relatively shallow water, certain fringing reefs have broadened more rapidly than most barrier and atoll reefs, which commonly face very deep water.

### *Glacial Controls over Reef Growth.*

For the sake of clearness the chief Glacial controls affecting the living coral reefs may be briefly reviewed. They are three in number:

1. Cooling of the tropical zone.
2. Repeated lowering of sea-level, involving three main consequences: *a.* Interference with reef growth through the special stirring of bottom sediment; *b.* Temporary location of the levels of marine abrasion and deposition at depths 50 meters or more below the present surface of the sea; *c.* Very great increase in the total length of the *edges* of shelves and detached banks where reef corals could take root (because of the temporarily diminished depth of water on banks).
3. Final rise of sea-level, lessening the turbidity of the water on banks and thereby ensuring long life for the reefs.

The principles noted under 2*c* and 3 operate in favor of the view that the present epoch is witnessing *a quite extraordinary profusion and prosperity of reefs, whether fringing, barrier, or atoll.* Because of Pleistocene marine erosion, shelf waters just offshore are now, in general, deeper and therefore purer than were pre-Glacial shelf waters at the same distance from shore. Equally important was the lowering of sea-level, because it so greatly increased the total linear mileage of shelf edges, where the water became shallow enough for the planting of reefs and yet was relatively free from deleterious sediment in suspension. The increase in the linear mileage of barrier reefs, compared with pre-Glacial barriers, has tended to increase the total linear mileage of fringing reefs also; for the barriers, now damping the open-ocean waves, are protecting the shore-waters of the great shelves from excessive turbidity to a degree not possible if the barriers did not exist. Hence a large percentage of the existing fringing reefs are healthily growing inside offshore barrier reefs.

### *Objections to the Glacial-control Theory.*

Many complications in the history of the modern reefs, apart from Glacial controls, have been described or suggested in the writer's 1915 paper, but some of them may

be mentioned here, since they have been thought to invalidate the theory of Glacial controls.[13]

1. *Evidence from Drowned Valleys.*—During post-Pliocene time the earth's crust, in the tropical belt, was not perfectly stable. Some areas in the coral-reef zone have sunk; others have risen. Warpings, illustrating both kinds of movement in one and the same crustal block, are practically demonstrated. Certain volcanic islands have been formed since the Pliocene. Many other volcanic islands have undergone deep trenching by streams. Doubtless some of the younger volcanic islands have recently sunk, for the special reasons already noted. Certain embayments seen in volcanic islands, as well as exceptional depths in lagoons, such as 70 fathoms at Vanikoro, may possibly be thus explained.

Yet the proof of recent local movements of the kind is far from being a proof of subsidence as a general cause of atolls and barrier reefs. Much more weight should be given to the highly specialized relations existing between reefs on the one hand and shelves and detached banks on the other.

The objection to the Glacial-control theory, based on the existence of drowned valleys, loses force when it is recognized that the Tertiary and later subsidence, so demonstrated for some central islands and for certain continental coasts, is not necessarily connected with the upgrowth of living reefs. As previously explained, embayments due to pre-Glacial, local subsidence may have lost much of their detrital filling through Pleistocene erosion and thus may resemble embayments caused by quite recent drowning of valleys. That the drowning in several instances is to be dated well before the dawn of the Glacial period is proved by the width of the shelves fronting those bays. Many other embayments have size and form appropriate if they have been caused by a rise of sea-level no greater than that taking place since maximum glaciation. In fact, the latter group seems to testify to the probable soundness of an important element in the Glacial-control theory of reefs, namely, the temporary but prolonged lowering of base-level of tropical streams.

[13] See especially W. M. Davis, Journal of Geology, vol. **26**, pp. 198-222, 289-309, 385-411, 1918; and Bull. Geol. Soc. America, vol. **29**, pp. 489-574, with bibliography, 1918.

2. *General Absence of Spur-end Cliffs.*—The bays caused by the drowning of valleys in pre-Glacial time had no such limitations of width and depth. Soon after their development, the adjacent hill spurs or capes would normally be protected by fringing reefs during the late Tertiary. According to the foregoing brief analysis of Glacial and Recent conditions, few of these spurs should now show high cliffs above the sea. The spurs were defended against Pleistocene wave abrasion until much time had elapsed in the scouring and re-gradation of shelves, the destruction of Tertiary fringing reefs, and the much slower benching of the underlying, generally much more resistant, rock. Cliffs cut in the foundation rock would have to be 30 to 60 or more meters high in order now to appear above sea-level. From the little that is known regarding the rate of cliff-recession in hard lavas and granites, one may well doubt the ability of Pleistocene abrasion to do so great a work in the average case. If cliffs so high were generated in the first glacial stage, their summits have undergone weathering and wasting ever since and, unless refreshed, might have already faded out more or less completely. Protection by interglacial reefs is another of the problems difficult to estimate.

The essential point is that the Glacial-control theory does not demand extensive benching of hard-rock islands during the Glacial period, even if its total duration were one million years. The widths of drowned-valley embayments do not imply any conclusion whatever concerning the amount of cliff recession on Pleistocene shores. Nor is there any implied relation between the widths of drowned-valley embayments and the widths of the platforms on which the modern reefs have grown. In the writer's judgment these platforms are chiefly due to the smoothing and extension of *banks* by Pleistocene marine gradation, and not to extensive wave-benching of formations as hard as lavas or ordinary continental rocks. The broad platforms which were essentially prepared by wave erosion in hard rocks must date from periods long before the Glacial epoch; in these instances also the Pleistocene waves and currents did little more than smooth off any veneer of organic deposits or of detritus lying on the wave-cut flats. In brief, Pleistocene wave abrasion merely "sand-papered" structures of which

the heavy sculpturing or accretional formation had been accomplished long before.[14]

3. *Evidence from Cliffed Islands.*—If reefs have not been successfully planted on a pre-Glacial volcanic island, its lavas suffered abrasion in pre-Glacial time as well as during the whole Glacial period. Lacking reef protection during the interglacial stages, the island has probably had an erosion history different from that of most islands in the coral-reef zone. Partially drowned Pleistocene cliffs, modified by Recent erosion, might be expected. Tahiti, Tutuila, Reunion, and Hawaii seem to be examples of such exceptional islands. Why are they exceptions?

The delay in finding reef protection is conceivably due to one or more of several causes:

*a.* Situation of the island near the border of the temperature zone where corals can flourish, rendering successful reef growth impossible because of intermittent chilling of the shore region by shifts of currents.

*b.* Failure of colonization by corals, owing to the fact that prevailing currents have not been charged with coral larvae.

*c.* Too great abundance of detritus on the island shores, tending to smother coral plantations—a principle specially emphasized by A. Agassiz in his description of the Marquesas islands, the Galapagos group, Mehetia, etc. (See Memoirs, Mus. Comp. Zool., vol. 28, p. 4, 1903.) Several conditions make for turbidity of the shore water. If the island is largely composed of volcanic ash and agglomerate, both subaerial and marine erosion unite in increasing the supply of shore detritus faster than if the island were entirely composed of lava flows.[15] Other things being equal, great altitude for the island tends to speed up the delivery of stream-borne detritus to the shore belt. Other things being equal, the larger the island the more rapidly is land waste supplied to the shore belt, because the gathering ground for the waste from an island of constant shape increases as the square

[14] The Glacial-control theory by no means implies that the great Macclesfield Bank is the root of a volcanic island first truncated by Pleistocene waves (as stated by W. M. Davis, Bull. Geol. Soc. America, vol. 29, p. 520, 1918).

[15] Hence one must study the petrography of each island before drawing conclusions as to its fitness to support reefs.

of the island's radius, while the length of the shore-line increases directly as the radius.

*d.* Exceptionally heavy rainfall, inducing rapid stream erosion, accelerates the delivery of detritus to the shore belt.

*e.* The members of the Siboga expedition found that coral growth was prevented on a large bank, south of Saleyer island, by the smothering action of loose débris of algae, especially *Halimeda*.[16] Possibly the same kind of inhibition affects some tropical islands.

*f.* Other, as yet unsuspected reasons for the local failure of coral growth may work singly or in cooperation with the known causes.

New Caledonia, Hawaii, Tahiti, Reunion, and Tutuila—examples of strongly cliffed islands—show a combination of factors noted in the foregoing list. In particular, they are characterized by high altitude; long, steep slopes; and relatively large areas.[17] These features doubtless characterized all five islands since the beginning of the Glacial period. Only recently were more favorable conditions established, with the last rise of sea-level, drowning Pleistocene valleys, re-drowning some pre-Glacial valleys, and trapping much land detritus in the bay deltas. As already observed, Pleistocene gradation of the offshore shelves had also prepared the condition for special purity of the shore waters at present sea-level. Moreover, the shelves around Tahiti and Tutuila could not become the sites of stable barrier reefs until the shelves had been sufficiently broadened. They were broader at the close of the last glacial stage than ever before.

Thus, there seem to be good grounds for interpreting the exceptional, cliffed islands of the tropical zone without abandoning the hypothesis of some oceanic chilling and inhibition of reef growth during the Glacial period. Nor is it necessary to assume, in each case, a rapid, strong, Recent subsidence of the island. On the other hand, the boring made under Mayer's direction on the Tutuila reef discovered volcanic rock at a depth appropriate to the Glacial-control theory.

[16] A. Weber and M. Foslie, Siboga-Expeditie, Corallinaceae, Leiden, p. 6, 1904.

[17] Obviously the argument does not imply that all small islands should be reefed, nor that all large islands should be reefless.

The argument just presented implies explanation for the cliffless Murea, a close neighbor of Tahiti; for of the two Murea is both smaller and lower. Perhaps its petrography is significantly different. However, even if Tutuila, Murea, or Tahiti were proved to have sunk recently, there would still be little warrant to extend the explanation by subsidence to barrier reefs and atolls generally. The fundamental objections to Darwin's theory, founded on the forms of reefs, lagoons, and submarine banks, would have lost practically nothing of their force; and these objections have not yet been overcome.[18]

4. *Depths of Lagoons.*—Variation in the depths of lagoons has been charged against the Glacial-control theory. Yet variations within limits are positively demanded by that theory.

The pre-Glacial shelves, benches, and banks had surface levels varying because of: differing absolute age; differing duration of their exposure to marine abrasion as well as marine aggradation; differing constitution, so that a muddy shelf would be covered with water deeper than that expected on a sandy shelf, to say nothing of a rock bench—all formed under similar conditions of wave and current strength; crustal warping, etc.

The submarine flats "sand-papered" by Pleistocene abrasion and the new Pleistocene detrital shelves would also have initially varying depths below present sea-level, for the same reasons, to which must be added the complications induced by repeated changes of wave-base and current-base during the Glacial period.

On those initial plateaus are veneers of post-Glacial detritus and organic growths; the veneers can not be uniform in thickness.

Hence, for at least three sets of reasons, lagoon depths should not now be uniform, if developed according to the terms of the Glacial-control theory. The theory does

[18] For example, no effective reply has been made to one deep-seated trouble with the subsidence theory. The ocean charts fail to show even one well-defined "moat" inside barrier or atoll reef, as foretold by the theory. Lagoon waves are weak and said to be "nearly negligible" (Davis) as cliffing agents; hence they are unlikely to aggrade wide, deep lagoons so rapidly as in all cases to obliterate the "moat." Lagoon waters do, of course, become turbid with suspended sediment during storms, but this sediment is normally obtained in the shallows and the turbidity does not at all prove the ability of the waves to stir sediment already deposited in the larger, deeper part of the lagoon. Appeal to lagoon currents as agents competent to obliterate moats with sufficient rapidity is no more successful.

demand: a rule of comparatively small depth for lagoons; and flat floors for wide lagoons, at levels slightly higher, on the average, than those characterizing the tops of most extra-tropical banks. The theory by no means excludes the occasional discovery of exceptional depths even inside barrier and atoll reefs, where constructional hollows—drowned valleys, fault-troughs, volcanically formed depressions—have not yet been filled with detritus. In fact, the rarity of lagoon depths greater than 50 or 60 fathoms strongly suggests a lack of extensive subsidence of the sea-floor for the last hundred thousand years, if not for the last million years or more. The local, Recent subsidence of a Vanikoro or of part of the Tonga plateau are exceptions merely proving the rule.

Again, uplift has recently (in the late Wisconsin stage or later?) shallowed some lagoons. Examples are given in the writer's 1915 paper. Others are North Argo lagoon and Ngele Levu lagoon of the Fijis, each bearing islets of elevated limestone. These two cases have been cited as evidence against the Glacial-control theory, on the ground that their lagoon depths are abnormally small. Since they have been recently uplifted, the lagoon floors should be nearer the present sea-level than similar floors which have undergone no displacement in late-Glacial or post-Glacial time. In reality, the study of exceptional cases here also seems to prove the rule of long-continued and nearly perfect crustal stability for most of the oceanic areas in the tropics.

5. *Crustal Movements in Areas Near Coral Reefs.*—Conclusions demanding instability in a sea area because neighboring lands have recently moved up or down ought to be made very conservatively. If one judged from the recent, gigantic warpings proved in the Timor-Ceram region by Molengraaff and others, he might be tempted to deduce recent crustal uneasiness in the adjacent, western part of the same "Eastern" archipelago. Yet the charts show that the broad area from Java to Siam and Annam has been stable nearly enough and long enough for the generation of one of the greatest continental shelves on the globe. Molengraaff himself has emphasized a long crustal stillstand in the Java Sea area, as implied in his view that it suffered peneplanation.[19]

[19] G. A. F. Molengraaff, Proc. kon. Akad. Wet., Amsterdam, vol. 19, p. 612, 1916.

Similarly, Abendanon assumes (Oligocene) peneplanation of Celebes, as noted by Davis.[20] The wide shelf west of Palawan island means prolonged crustal stability for the eastern part of the China Sea area—a crustal quiescence which followed a period of crustal unrest both in the Philippines and in Malaysia. The question is as to which period or process most affects the problem of the living coral reefs. If any inference from the lands bordering the China Sea is permissible, it is more relevant to assume recent, prolonged stillstand at the Macclesfield Bank and the other great banks thereabouts than to assume recent subsidence. The full duration of effective crustal stillstand cannot yet be expressed in terms of geological periods, much less in years, but it need not be any longer than the "long stationary period" or a "long interval of rest" postulated by Darwin to explain the flatness of lagoon floors and other, associated features.

6. *Assumed Uniformity of Reef Growth.*—Objection has been made to the Glacial-control theory on the ground that it demands for existing reefs uniform growth, uniform breadths, and uniform heights above platforms. The mere statement of the test shows that it is unreasonable. The volumes of the living reefs, measured above the levels of their theoretical platforms, depend on many highly variable factors, which may be listed: *a.* Date of colonization by reef organisms; *b.* Initial depths of the platforms; *c.* Depths of water where talus must accumulate in order to support reefs which have been growing outwards; *d.* Amount of food supply for reef organisms; *e.* Density of the plankton and shallow-water, non-coral population furnishing débris to the growing reefs; *f.* Distribution of hurricane tracks and other oceanic phenomena affecting the welfare of reefs; *g.* Recent crustal deformation; *h.* Character and abundance of each coral and algal species instrumental in the building of reefs.

Without further expanding the list and without laboring the point that all eight factors named are exceedingly variable throughout the tropical zone, one should have no difficulty of understanding why existing reefs are partly alive, partly drowned and dead; well developed at or near low-tide level, and in many other cases nowhere built up to that level; knolly, or continuous; narrow or relatively broad at any given level.

[20] W. M. Davis, Jour. Geol., vol. 26, p. 394, 1918.

The truth is that no living reef seems to have volume too great to be explained by reef growth in post-Glacial time, even though that time has had a duration of only 20,000 to 50,000 years. The more positive bearing of the subject is found in the closeness of the similarity in form and bulk among the reef ridges of normal atolls and barrier reefs throughout the Pacific and Indian oceans. The actual degree of likeness argues for a contemporaneous upward shift of sea-level in the whole tropical belt of the earth, just as the rough accordance of depths in the larger lagoons and on rimless banks argues for a former, prolonged, nearly constant relation of sea-level to the submarine reliefs.

In fact, the objection suggests another difficulty with the subsidence theory. To work at all, this explanation of reefs has to postulate "a long stationary period" during which each lagoon floor could be flattened by aggradation to the observed extent. Where so many structures of the kind have been developed, it would be a miracle if not one "mature reef-plain" (completely filled lagoon) of large size still remained at or near its level where the plain was formed. More generally, the theory of intermittent subsidence leads one to expect that somewhere there should be reefs *much* broader than the average and not yet sunk below the five-fathom line. But the world charts fail to exhibit such very wide reefs or large "mature reef-plains" at their original levels.

7. *Additional Objections.*—Other strictures on the Glacial-control theory have been attempted by the use of data from the Funafuti and Bermuda borings, from elevated "reefs" in Fiji, and from biological "proofs" of enormous land bridges in the mid-Pacific. Space here fails for discussion of all the points. The writer must be content with the statement that none of these arguments carries conviction. But concerning the Funafuti boring a word may be added.

According to Darwin's hypothesis of intermittent subsidence, the Funafuti atoll mass "long" stood still, while its lagoon was aggraded to a nearly level plain. During that "long" time, the main reef must have grown out on its own talus. Hence the lower part of the boring must have passed through talus; for, if the lagoon had received enough reef débris to fill a deep "moat" around a sinking volcano, the outer slope should have received enough to build out a talus at least as far as the width of

the present reef. Davis, another upholder of the subsidence theory, prefers the view that the lower part of the boring penetrated lagoon deposits; while Skeats, a third advocate, seems to think the boring remained throughout in "true reef."[21] Such failure of agreement illustrates the vital need of properly correlating upgrowth, lagoon filling, and the formation of external talus. The chance that the boring should remain throughout in "true reef" is exceedingly slight, if one may judge from the correlations so far made by special students of the problem. Moreover, the difficulty of stating what "true reef" is, and the still greater one of distinguishing it from reef-talus rock, are only now beginning to be thoroughly realized.

Skeats has tried to strengthen the case for the older theory by citing the discovery of dolomite in the deeper part of the Funafuti bore. He suggests that dolomite is formed only in "shallow" water and therefore concludes that there is new evidence for subsidence. However, his premise is subject to grave doubt, which is not lessened by an examination of his argument, based on the varying solubilities of carbonates in carbonated water under pressure. Mere pressure of overlying sea-water has almost no effect on the concentration of carbon dioxide; laboratory experiments made with water under pressure and saturated with the gas evidently do not reproduce the conditions in the ocean.

Omitting further discussion, the writer will simply express his adhesion to the opinion of some members of the Funafuti Committee, appointed by the Royal Society of London—that they found no confirmation of the subsidence theory in this rock-boring.

### *Summary.*

Conceivably the living coral reefs have been formed in several distinct ways, but, as observed in the writer's 1915 paper, plenty of facts tend to corroborate Darwin's conclusion that some one general explanation is demanded. Principles not organically connected with the general explanation may apply to the understanding of a reef here or there. These relatively few exceptions

[21] W. M. Davis, Jour. Geol., vol. 26, Fig. 1 and p. 208, 1918; E. W. Skeats, this Journal, vol. 45, p. 84, 1918.

should not obscure the validity of the more general theory.

Demonstration of the general process must wait on a double course of study—observation of sea, land, and organisms today, and reasoned inference regarding the condition of sea, land, and organisms at the successive stages of oceanic evolution. This paper specially stresses the latter, historical or geological, mode of attack. Its leading conclusions may be noted.

1. At the present time the tropical ocean is probably characterized by an exceptional abundance of vigorous coral reefs. In pre-Glacial time, atolls and barrier reefs were much rarer, if not entirely absent from the sea. Pre-Glacial fringing reefs were more in danger of smothering by sediment than are most existing reefs. Hence the Pliocene and older open-ocean islands may not have been nearly so well defended against marine abrasion (ultimate truncation) as the existing oceanic islands.

2. During Pleistocene glaciation, the prosperity, if not the life, of reef corals was threatened by two enemies: oceanic chilling and smothering by sediment. Perhaps killing by wave-stirred mud and sand was more important than the fall of oceanic temperature. The question is raised as to whether the Lithothamnia, so vital to reef strength, were also affected by these physical conditions in the Pleistocene ocean.

3. Working at levels lower than the present level, the ocean waves of the glacial stages benched the weak strata of the new coastal plains, the somewhat more resistant pre-Glacial reefs, and, in far less degree, the harder shore rocks. Tidal and other currents cooperated with the waves in smoothing the outer banks. The actual amount of cliffing now to be observed on tropical shores has been once more explained in order to clear up a serious misunderstanding of the Glacial-control theory. For a similar reason, the history of drowned valleys in islands and continents is again reviewed. While some drowned valleys betoken subsidence, their existence does not seem to be crucial in the problem of coral reefs.

A specially notable effect of the lowering of sea-level during glaciation is seen to have been the shallowing of water on the banks and shelves then existing, so that corals could take root on the edges of these submarine plateaus. In comparison, the platforms due primarily to Pleistocene abrasion are less important.

4. Careful study of the geological dates so far determined for crustal movements in and around the western tropical Pacific permits explanation of the Macclesfield and other banks in that region by the new theory; their explanation does not appear to call for crustal subsidence since the late Tertiary. In general, the Glacial-control theory demands crustal stillstand no more prolonged or but little more prolonged than that demanded by any other theory of reefs yet published. The latest theory demands general stability of the earth's crust in the tropical belt only for the last few hundreds of thousands of years, during which, however, local instability has been pronounced, with effects whose study actually strengthens the new theory. General subsidence of the tropical-sea floor may have occurred in pre-Glacial time, but, if so, we have no proof of it—especially no proof in the forms of the existing coral reefs. On the other hand, the hypsometry of the wider lagoons and banks, reef-rimmed or not, suggests stability for most of the tropical-sea floor since at least the late Miocene.

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# SCIENTIFIC INTELLIGENCE.

## I. Chemistry.

1. *A System of Physical Chemistry;* by William C. McC. Lewis. In Three Volumes; Vol. III, Second Edition. *Quantum Theory.* 8vo, pp. 207. London, 1919. (Longmans, Green & Company. Price $2.50 net.)

In the last thirty years, there has been an enormous increase in the quantitative data of physical chemistry. Along with this increase, have come attempts, many remarkably successful, to account for the facts observed. Van't Hoff's and Arrhenius' theories of dilute solutions and Nernst's heat theorem are well-known illustrations in point. Planck's quantum theory is a modified system of statistical mechanics which was proposed originally to account for some of the facts of radiation. The theory has more recently found application in other ways, such as in the explanation of the heat content of substances and the variation of heat content with temperature.

Professor Lewis, in his book, presents very well indeed what has been accomplished by applying the quantum theory and he reviews much of the literature on the subject, which is not yet so extensive as to make this impracticable. The theory and its application are not simple but the book can be recommended to students who wish to enter this field. H. W. F.

2. *An Introduction to the Physics and Chemistry of Colloids;* by Emil Hatschek. 12mo, pp. 116. Philadelphia, 1919 (P. Blakiston's Son & Co. Price $1.50 net).—This is the third edition of a useful little book of British origin, giving a very satisfactory outline of the fundamental facts, theories, and methods of investigation of this increasingly important branch of chemistry. It is a book that can be highly recommended to students of chemistry who wish to familiarize themselves with the points of view, the technical terms and the important practical applications of the subject. H. L. W.

3. *Colloidal Chemistry;* by Jerome Alexander. 12mo, pp. 90. New York, 1919 (D. Van Nostrand Company. Price $1.00 net).—This little book by an American author gives a very satisfactory introduction to the subject. The author states that he has attempted to compress within very limited space the most important general properties of colloids and some of the practical applications of colloidal chemistry, and it is his hope that it will be helpful in extending the sphere of interest in this fascinating twilight zone between physics and chemistry. There is no doubt that the book is an excellent one for its purpose and attention may be called particularly to the fact that more than one-half of its contents is devoted to a very interesting discussion of the practical applications of colloidal chemical principles.

H. L. W.

4. *Chemical Calculation Tables for Laboratory Use;* by HORACE L. WELLS. 8vo, pp. 43. New York, 1919 (John Wiley & Sons, Inc., $1.25 net).—This is the second edition, revised and considerably modified, of a little book intended particularly for the use of students and practitioners of analytical chemistry in making logarithmic calculations. It gives tables of atomic weights, gravimetric and conversion factors, formula weights, multiples of the atomic weights of the elements commonly occurring in organic compounds, as well as a few other useful tables, including a five-place table of logarithms of numbers which is provided with a convenient double thumb-index. The present edition is printed on bond paper in order that it may be durable. The employment of this book should make the work of accurate calculation more rapid and less laborious than is often the case.

## II. GEOLOGY AND NATURAL HISTORY.

1. *The U. S. Geological Survey. Its History, Activities and Organization.*—Service Monographs of the U. S. Government, No. 1. Published by the Institute for Government Research, Washington, D. C., and printed by D. Appleton and Company, New York, 1918. No author is given.—"The Institute for Government Research is an association of citizens for coöperating with public officials in the scientific study of administrative methods with a view to promoting efficiency in government and advancing the science of administration." The visible part of the Institute consists of six officers and eighteen trustees. In this book is given the history and development of the early explorations leading up to the present Survey; and the functions, organization, and laws and regulations which govern the latter. There is also a full bibliography of the sources of information, official and private, bearing on the service and its operations. The study is wholly descriptive in character, and no attempt is made at criticism. It is a very readable account of what the U S. Geological Survey is doing, as seen by disinterested parties. C. S.

2. *Manual of the Chemical Analyses of Rocks;* by HENRY S. WASHINGTON. 3d edition. 8vo, pp. 269. New York, 1919 (Wiley & Sons).—In the last twenty years a notable improvement in analytical work on minerals and rocks may be observed, and especially with respect to rocks. On the one side, this is owing to the development of superior methods of analyses, apparatus, reagents, etc.; but on the other, with rocks, it has largely been due to a general inculcation of higher standards of work, and a demand for more complete and exact results. This general betterment in rock analyses we owe in great measure to the work and writings of the author of the book before us. This manual has become so well known to petrologists and analy-

tical chemists in the two previous editions, issued in 1904 and 1910, that it seems only necessary to call attention to the appearance of this new edition. The general plan and scope of the book remain unchanged; the fullness of detailed instructions for the carrying out of analytical processes is the same, and many valuable suggestions are made whereby time and effort may be saved.

In addition, however, new analytical methods, or improvements of older ones, are added, as well as complete details for the estimation of more of the rarer elements in rocks. With this work at hand the chemist, or petrologist, who has had some training and experience in analytical work, need have no fear, if he follows the orderly plan laid down with fidelity, but that his results will be of a high order of excellence.

Moreover, the book is an excellent one to put into the hands of the student, when he has made some little progress in analytical chemistry, and is ready to undertake the analysis of a silicate. It has, indeed, been written quite as much from the standpoint of helping the beginner, as of providing methods for the skilled analyst. The details of methods are, therefore, more fully treated than in the former editions, while possible errors are thoroughly considered. The book should have a place in the working reference library of every analytical laboratory, as well as in that of the petrologist. L. V. P.

3. *A Source Book of Biological Nature-Study;* by Elliot Rowland Downing. Pp. xxi, 503, with 338 figures. Chicago, 1919 (University of Chicago Press).—This is one of a series of guides for teachers of nature studies in the secondary schools and for students in normal schools and schools of education who are preparing for such teaching. The volume is filled with practical information about common forms of life, with useful suggestions for imparting this information to the pupils in such a manner as to stimulate their observation of their surroundings.

The teacher is shown how to guide the pupil in acquiring a personal acquaintance with the animals of pond and stream, and with insects, birds, pets, flowers, weeds, trees, seeds, garden crops and fungi. The utilitarian aspects of the subject are emphasized at all times and the pupils encouraged to put their knowledge to practical use in their homes and in the community generally. Such training as is implied by studies of this character can hardly fail to encourage in the pupil a sense of responsibility for the public welfare and an ambition to become a useful as well as an intelligent citizen. W. R. C.

4. *Problems of Fertilization;* by Frank Rattray Lillie. Pp. xii, 278, Chicago, 1919 (University of Chicago Press).—The author has rendered a conspicuous service to biology in presenting in this convenient form a summary of his own studies in a field in which he has long been a leading investigator.

The philosophical significance of fertilization, the morpho-

logical changes and physiological processes involved, together with the physico-chemical phenomena concerned in specificity and activation are fully discussed, with reference to the more recent publications on this important subject. W. R. C.

## III. Miscellaneous Scientific Intelligence.

1. *Division of Geology and Geography of the National Research Council.*—This Division has been organized to render service to investigators in these subjects. It proposes:

1. To assist scattered individual workers to get in touch with other workers in the same or allied fields and thus avoid duplication and to coördinate investigations in the same subject;
2. To coöperate in the promotion of promising lines of research by securing coördination and participation of workers in the same or allied lines;
3. To bring promising projects of research to the attention of those who may be willing to assist financially or otherwise; and
4. To stimulate research by the proposal of problems forming parts of comprehensive schemes involving more than one branch of scientific inquiry.

To these ends it offers its facilities for bringing together information regarding pending investigations or the personnel of those interested in a given problem, and its judgment of the value of proposed investigations in the light of what is being done elsewhere. The Division aims to act as an aid and clearing house to eliminate lost motion and increase efficiency without the assumption of direction or dictation of the methods or means employed or a judgment of the ultimate results. While it is not primarily an agency for financial support, it proposes to develop or direct funds towards the assistance of worthy investigations whenever this is possible.

The preliminary circular letter, from which the above paragraphs are quoted, is signed by Professor Edward B. Mathews as Acting Chairman. The National Research Council was organized on a peace basis in the early part of 1919 by Executive order of the President of the United States.

2. *Recent publications of the Carnegie Institution of Washington* (continued from vol. **47**, p. 83):

No. 249, Part III. Displacement interferometry by the aid of achromatic fringes; by Carl Barus. Pp. 100, 74 figs. in text.

No. 259. Naval Officers, their heredity and development; by Charles B. Davenport, assisted by Mary T. Scudder. Pp. 236.—Sixty-eight selected naval officers furnish the data from which the conclusions given are deduced.

No. 264. An analysis of the effects of selection; by A. H. STURTEVANT. Pp. 68, with frontispiece, text figures and tables.

No. 265. Duration of the several mitotic stages in the dividing root-tip cells of the common onion; by HARRY H. LAUGHLIN. Pp. 48, with charts, diagrams and tables.

No. 266. Effect of alcohol on psycho-physiological functions; by WALTER R. MILES. Pp. 144.

No. 267. The atomic weights of boron and fluorine; by EDGAR F. SMITH and WALTER K. VAN HAAGEN. Pp. 65.

No. 269. The fruit of *Opuntia fulgida;* a study of perennation and proliferation in the fruits of certain Cactaceæ; by DUNCAN S. JOHNSON. Pp. 62, 12 pls. and frontispiece.

3. *New Outline Map of the United States on the Lambert Projection.*—The U. S. Coast and Geodetic Survey reports the completion of the new outline map of the United States on the Lambert Conformal Conic Projection, scale 1-5,000,000, dimensions, 25 × 39 in. (price, 25 cents). This map is intended as a base to which may be added any kind of special information desired. The shoreline is compiled from the most recent Coast and Geodetic Survey charts. State names and boundaries, principal rivers, capitals and largest cities in the different states, are the only information otherwise embodied. The map is of special interest from the fact that it is based on the same system of projection as that which was employed by the armies of the allied forces in the military operations in France. To meet those requirements and at the request of the Army, special publications were prepared by the Coast and Geodetic Survey.

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2. The meridians are straight lines and the parallels are concentric circles.

3. It has two axes of strength instead of one, the standard parallels of the map of the United States being latitudes 33° and 45°, and upon these parallels the scale is absolutely true. The scale for any other part of the map, or for any parallel, can be obtained from Special Publication No. 52, page 36, U. S. Coast and Geodetic Survey. By means of these tables the very small scale errors which exist in this projection can be entirely eliminated.

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# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

## Art. XI.—*Wollastonite ($CaO.SiO_2$) and related Solid Solutions in the Ternary System Lime-Magnesia-Silica;* by J. B. Ferguson and H. E. Merwin.

Contents.



### Introduction.

In a previous paper[1] the general temperature-concentration relations found in the ternary system "Lime-Magnesia-Silica" have been given, and in this paper we wish to present a particular discussion of the calcium metasilicate and related solid solutions which could not be adequately discussed in the more general paper.

The accuracy and definiteness of a large part of the work herein presented is much less than in the previous work on account of the following causes: difficulty of identifying certain phases not only because of fineness of grain but also because of their great optical similarity;

[1] This Journal, August number, 1919.

sluggishness of inversion; and the presence of unstable phases.

The optical properties of these phases have been given in the previous paper and will be given only incidentally here, but a résumé of other previous work is as follows: According to Rankin and Wright[2] pure wollastonite (calcium metasilicate, $CaO.SiO_2$) inverts at 1200°C to a high-temperature form, pseudowollastonite. Excess of silica in solid solution raises the inversion temperature 10° and an excess of tricalcium disilicate lowers this temperature 10° (or more). According to Allen and others,[3] wollastonite forms solid solutions containing a maximum of 17 per cent of diopside ($CaO.MgO.2SiO_2$) with a maximum rise of the inversion temperature to about 1345 ± 10°C.[4]

The liquidus-solidus relations found by us in the ternary system do not agree with the rather simple solidus relations hitherto inferred; furthermore, subsequent study has shown that the solidus relations also are very complex.[5] For reference these relations are given in fig. 1.

## Experimental Part.

*Methods.*—The study of the purely solidus relations was made by first preparing glasses of the desired compositions and then crystallizing these glasses at low temperatures. In general, the glasses usually gave some unstable pseudowollastonite when crystallized at a temperature just below the stability region of this form of calcium metasilicate. To avoid this difficulty, the glasses were first heated over night at 800 to 900°C which caused them to crystallize, often not completely, and then heated for some hours at a temperature just below the inversion temperature of the particular charge in question. This subsequent heat treatment caused the crystals to grow somewhat and made possible a selection of material nearly free from pseudowollastonite.[6] The need for such care in the selection of material arose from

[2] Rankin and Wright, this Journal (4), 39, 1, 1915.

[3] Allen, White, Wright, and Larsen, this Journal (4), 27, 19, 1909.

[4] Grundlagen der physikalisch-chemischen Petrographie, 182, 1915.

[5] It is hardly necessary to point out that different forms of the same compound are distinct phases, and their ranges of solid solution are not necessarily the same.

[6] Charges containing disturbing amounts of pseudowollastonite were discarded and when necessary the heat treatments were repeated with a fresh sample of glass.

the fact that the low temperature forms readily invert to the higher temperature forms but the reverse operation does not take place in a reasonable time. The microscopic determination of inhomogeneity was at times impossible because of the similar optical properties of the crystalline phases present. In these cases the changes in the

Fig. 1.

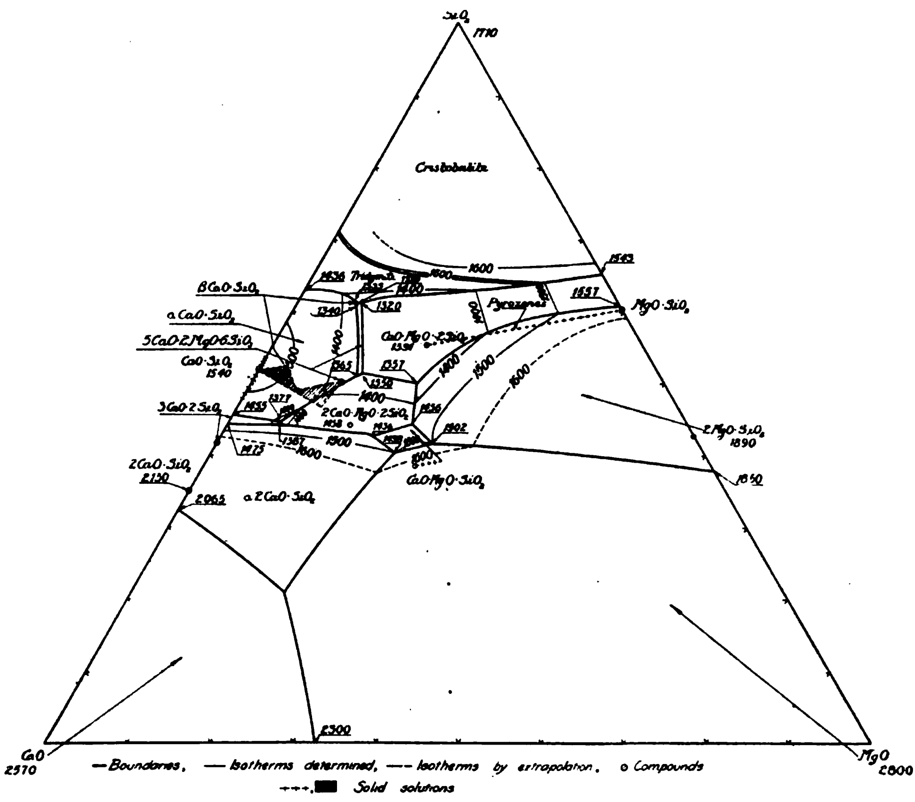



Fig. 1. The triangular concentration diagram of the system CaO-MgO-$SiO_2$ showing the location of the fields, the fixed points and their temperature relations.

inversion temperatures of the low-temperature forms were assumed to indicate the extent of the solid solutions.

*Solid Solutions of $CaO.SiO_2$ with Silica.*—The following observations were made to determine the extent of these solid solutions:

(1) A charge with composition CaO 45, $SiO_2$ 55, which

had been crystallized at low temperatures by Mr. E. S. Shepherd of this Laboratory, was examined and found to contain wollastonite with definite traces of silica. The weight percentage composition of wollastonite is CaO 48.2, $SiO_2$ 51.8.

(2) A glass with composition CaO 46, $SiO_2$ 54, was heated for 40 hours at 1000°C. Upon examination it was found to have crystallized to a milky wollastonite and had minute traces of pseudowollastonite in it. The charge appeared under the microscope quite brown as did the previous charge but in this case no absolute identification of silica could be made.

(3) A glass with composition CaO 47, $SiO_2$ 53, was heated 16 hours at 1065°C. The glass originally contained a trace of pseudowollastonite. After the heat treatment much wollastonite could be identified but no silica.

(4) A similar glass to that used in (3) was heated for several hours at 1400°C. It crystallized to pseudowollastonite and silica. The silica could be positively identified.

These experiments indicate that wollastonite takes up about 3 per cent[7] of silica (figured on the total weight) in solid solution, and that pseudowollastonite takes up less than 2 per cent.

*Solid Solutions of $CaO.SiO_2$ with $3CaO.2SiO_2$.*—Some confusion has arisen over the nomenclature of these solutions. Their compositions have generally been given on a component oxide basis and thus they have been referred to as solutions of lime in the metasilicate. In reality they are solid solutions with the compound $3CaO.2SiO_2$. When their compositions are given upon an oxide basis their true character is concealed since a solid solution containing a few per cent excess lime over the metasilicate composition is in reality a solution containing many per cent[8] of the compound $3CaO.2SiO_2$ and thus what is really a concentrated solution is made to appear as a somewhat dilute one.

[7] Percentages of silica on the diagrams refer to total composition on an oxide basis. Three per cent on a metasilicate basis would be about 1½ per cent on an oxide basis.

[8] One per cent excess lime on an oxide basis represents, when referred to the compounds present, approximately 10 per cent of $3CaO.2SiO_2$. Unless otherwise stated per cent always means weight per cent.

*A. Experiments with the Pseudowollastonite Solid Solutions.*

(1) A charge of composition CaO 49, $SiO_2$ 51, was heated some hours at 1450°C. No $3CaO.2SiO_2$ could then be observed.

(2) A charge of composition CaO 50, $SiO_2$ 50, was heated several hours at 1460°C; a small quantity of glass was then visible.

The pseudowollastonite solid solutions extend therefore to between the compositions CaO 49, $SiO_2$ 51, and CaO 50, $SiO_2$ 50, and the latter composition may be taken as the approximate limit. This represents about 20 per cent of the $3CaO.2SiO_2$ compound.

*B. Experiments with the Wollastonite Solid Solutions.*

Glasses with compositions ranging from pure wollastonite to CaO 54, $SiO_2$ 46, when crystallized at temperatures below 1000°C, usually contain little if any pseudowollastonite, but even after prolonged heating at temperatures just below the inversion temperatures (1170-1200°C) are so fine-grained that positive identification of the phases present is impossible. A charge with the composition CaO 56, $SiO_2$ 44, when crystallized at low temperatures, was found to contain traces of calcium orthosilicate which is here unstable, but no other phases could be made out. These facts made necessary a different method of attack than that of the crystallization of the undercooled glasses, and for the purpose a study of the inversion and decomposition temperatures seemed the only feasible method. The following significant experiments were made in this study.

(1) Material—Composition CaO 51, $SiO_2$ 49, fully crystallized but containing practically no pseudowollastonite.

(*a*) Heated all night about 1180°C. Mostly changed to pseudowollastonite.
(*b*) Heated two hours at $1164 \pm 2$°C. Unchanged.
(*c*) Heated two hours at $1182 \pm 2$°C. Signs that the inversion had started.

(2) Material—Similar to material (1) but with composition CaO 54, $SiO_2$ 46.

(*a*) Heated two hours at $1164 \pm 2$°C. Unchanged.
(*b*) Heated one hour at $1182 \pm 2$°C. Largely inverted.

(3) Material fully crystallized containing no pseudowollastonite but trace of calcium orthosilicate, composition CaO 56, $SiO_2$ 44.

(*a*) Heated two hours at 1150°C. Unchanged.
(*b*) Heated two hours at 1185°C. Largely inverted.

From these inversion temperatures and rates it would appear that the composition CaO 54, $SiO_2$ 46, has a lower inversion than the composition CaO 51, $SiO_2$ 49, and also probably that the inversion temperatures of the compositions CaO 54, $SiO_2$ 46, and CaO 56, $SiO_2$ 44, were approximately the same. We have therefore placed the limit of the wollastonite solid solution at the composition CaO 47.5, $SiO_2$ 52.5, or approximately 45 per cent of the compound $3CaO.2SiO_2$. This figure is not at all exact but seems the most probable value and is given in order to emphasize the fact that the extent of these wollastonite solid solutions is much greater than the earlier observations indicated. The most concentrated of these solutions inverts, or perhaps better, decomposes, at about 1170°C or about 30°C below the inversion temperature of the pure compound.

In discussing these and the other solid solutions it is somewhat difficult to draw the line between the use of the words inversion and decomposition. In what follows we will apply the word "inversion" to the phenomenon in which one solid phase changes into another, and "decomposition" to the phenomenon in which one solid phase changes into two or more phases, one of which at least is solid. Thus some of the wollastonite solid solutions with $3CaO.2SiO_2$ invert to form solid solutions of pseudowollastonite, and others decompose to form mixtures of a pseudowollastonite solid solution and the compound $3CaO.2SiO_2$.

*Solid Solutions of $CaO.SiO_2$ with Diopside.*—Solid solutions between pseudowollastonite and diopside have not been previously observed. The following experiments indicate that such solid solutions exist and extend to a composition containing about 16 or 17 per cent of diopside by weight.

(1) A charge with composition CaO 44, MgO 3.5, $SiO_2$ 52.5, was heated 16 hours at 1370°C. It then contained a small amount of glass with pseudowollastonite.

(2) A charge with composition CaO 44.4, MgO 3.1, $SiO_2$ 52.5, was heated 16 hours at 1370°C. Only pseudowollastonite could then be found in the charge.

(3) A charge with composition CaO 44.8, MgO 2.8, $SiO_2$ 52.4, was given the following two heat treatments:

(*a*) Heated for 15 minutes at 1500°C. Charge contained crystals of pseudowollastonite with a little glass.

(*b*) Heated for 15 minutes at 1510°C. Charge now glass with a few crystals scattered through it.

Wollastonite is known to form solid solutions with diopside taking up a maximum of 17 per cent of the latter at the higher temperatures. The decomposition temperature[9] of the most concentrated solution lies between 1336 and 1352°C. Our experiments confirm these earlier observations. They are given in Table I.

TABLE I.

The wollastonite-diopside solid solutions.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in hours | Phases present |
|---|---|---|---|---|---|
| 44·8 | 2·8 | 52·4 | 1290 | 15 | No diopside |
| 44·4 | 3·1 | 52·5 | 1340 | 15 | Homogeneous wollastonite |
| | | | 1346 | 0·75 | Trace pseudowollastonite and (?) |
| | | | 1336 | 2 | Wollastonite |
| | | | 1352 | 0·5 | Part charge changed to pseudowollastonite and (?) |
| 44 | 3·5 | 52·5 | 1300 | 15 | Wollastonite + diopside (less than 5%) |
| 46·6 | 1·6 | 51·8[1] | 1225 | 15 | Practically all wollastonite |
| | | | 1245 | 15 | Wollastonite and pseudowollastonite |

[1] Not quite on the line.

*Solid Solution toward Åkermanite.*—Solid solutions occur to a considerable extent in the binary system calcium metasilicate-åkermanite. The evidence that pseudowollastonite forms such solid solutions is as follows:

[9] We cannot say whether the extent of the solid solutions of diopside in pseudowollastonite is the same as, slightly greater than, or slightly less than that of the solid solutions in wollastonite since the limits are so close together. However, we have assumed that pseudowollastonite takes up a little less of diopside than does wollastonite and hence use the term decomposition temperature. Assumptions of this character are made, in this paper, purely to aid in the presentation of the experimental matter, the writers believing that in these cases a thorough discussion of all the possible interpretations of all of the evidence is unnecessary if one interpretation is given and other possible interpretations indicated but not worked out.

(1) A charge with composition CaO 46.7, MgO 3.1, $SiO_2$ 50.2, was given the following heat treatments:

(*a*) Heated 15 minutes at 1500°C. All glass.

(*b*) Heated 15 minutes at 1490°C. All consists of crystals of pseudowollastonite.

(2) A charge with composition CaO 46, MgO 5, $SiO_2$ 49, was heated for several hours at 1425°C and then found to contain considerable quantities of glass.

The approximate limit, therefore, assigned to the pseudowollastonite solid solutions is the composition CaO 46.5, MgO 3.5, $SiO_2$ 50, or about 23 per cent of åkermanite.

The experiments upon the wollastonite solid solutions are somewhat unsatisfactory since charges free from pseudowollastonite were so fine-grained that the phases then present could not be identified. Charges ranging from pure wollastonite to the composition CaO 43.5, MgO 10, $SiO_2$ 46.5, when free from pseudowollastonite appear homogeneous, but a charge with a composition CaO 42, MgO 13, $SiO_2$ 45, after an all-night heat treatment at 950°C, appeared brownish and not at all homogeneous, although no åkermanite could be definitely identified. We have placed the approximate limit of the solutions at the composition CaO 43.5, MgO 10, $SiO_2$ 46.5, which is very near the composition $3CaO.MgO.3SiO_2$, and corresponds to a composition containing between 60 and 70 per cent of åkermanite. There is no conclusive evidence to show whether these solutions are in reality solutions containing åkermanite or an unstable compound $3CaO.MgO.3SiO_2$, and lacking such evidence we have preferred to omit reference to this possible compound in the former paper and will in this paper assume it to be non-existent. The inversion and decomposition temperatures of these solutions are indicated by the quenches given in Table II.

TABLE II.

**Quenches which indicate the inversion and decomposition temperatures of the wollastonite-åkermanite solid solutions.**

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in hours | Phases present |
|---|---|---|---|---|---|
| 46·7 | 3·1 | 50·2 | 2103 | 0·5 | Initial charge of wollastonite unchanged |
| | | | 1213 | 0·5 | Inversion started |
| | | | 1225 | 2·0 | All pseudowollastonite |
| 43·5 | 10 | 46·5 | 1200 | 0·5 | Initial charge unchanged |
| | | | 1213 | 0·5 | Initial charge unchanged |
| | | | 1225 | 0·5 | All decomposed |

*Solid Solutions with Diopside and Silica.*—Several experiments were carried out in order to determine if any solid solutions existed between the calcium metasilicate-diopside line in the ternary system and the metasilicate-silica part of the side line. For this study the composition CaO 46.2, MgO 1.2, $SiO_2$ 52.6, was used.

Wollastonite: Heated at 1000°C for 40 hours. The charge then consisted of wollastonite which appeared brown under the microscope, evidently due to the presence of silica.

Pseudowollastonite: Heated at 1400°C for 2 hours. The charge then contained pseudowollastonite and no evidence indicating the presence of silica was obtained.

Evidently the wollastonite solid solutions do not extend appreciably from the diopside line toward the side line. The pseudowollastonite solid solutions on the contrary do extend somewhat in this direction but the limits of the solutions on the diopside line and on the side line preclude any great amount of solid solution in this region.

*Solid Solutions between the Wollastonite-Diopside and the Wollastonite-Åkermanite Solid Solutions.*—The optical similarity of all the pseudowollastonite solid solutions makes impossible a determination of the extent of these solutions in the region under discussion by means of the microscope. However, if no solid solutions exist within this region, then the region should consist of two fields, one for each series of solid solutions with the usual type of boundary curve.[10]

In the results upon the liquidus relations of the whole ternary system given in the previous paper, no evidence of such a boundary exists. Several additional experiments were made in order to be sure that such a boundary might not be overlooked. The results are given in Table III.

TABLE III.

Quenches which indicate the extent of the area of solid solutions of pseudowollastonite.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in min. | Phases present |
|---|---|---|---|---|---|
| 45·3 | 6·2 | 48·5 | 1450 | 30 | One-half glass |
| | | | 1470 | 30 | All glass |
| 44 | 6 | 50 | 1450 | 30 | Considerable quantity of crystals |
| | | | 1470 | 30 | Glass + trace of crystals |

[10] Ernst Jänecke, Zs. phys. Chem., 67, Case 2, p. 661, 1909.

For the investigation of the wollastonite solid solutions a study of the inversion temperatures was the only feasible method since the diopside and åkermanite solid solutions are optically very similar except for the sign and size of the optic axial angle. If no wollastonite solid solutions exist within the region in question, then any charge with composition lying within this region, if crystallized at low temperatures, should consist of a mixture of the two kinds of wollastonite solid solutions, and if the temperature be raised above the inversion temperature of one kind of wollastonite solid solution, then there should result a mixture of a pseudowollastonite solid solution and the other wollastonite solid solution. If, however, there is an area of solid solution, then for each solid solution of intermediate composition there will be a definite inversion temperature or interval of temperature.[11] The detection of an inversion temperature or interval of temperature differing from that of the solid solution of the bounding series would thus be proof of an area of solid solution. The inversion temperatures of the solid solutions of the two series are markedly different and thus enable one to obtain positive evidence on this point. This evidence is given in Table IV, and also some evidence upon the extent of the wollastonite solid solution in the region beyond that covered by the pseudowollastonite solid solutions.

TABLE IV.

Quenches which indicate the decomposition and inversion temperatures and the extent of the area of the wollastonite solid solutions.

| Composition wt. % CaO | MgO | $SiO_2$ | Temp. °C. | Time in hours | Phases present |
|---|---|---|---|---|---|
| 45 | 5 | 50 | 950 | 16 | All wollastonite |
| Previous charge reheated | | | 1220 | 0·5 | All wollastonite |
| Previous charge reheated | | | 1250 | 0·4 | Mainly changed to pseudo-wollastonite |
| 44 | 6 | 50 | 880 | 16 | Wollastonite with trace of pseudowollastonite |
| Previous charge reheated | | | 1260 | 0·5 | Unchanged |
| Previous charge reheated | | | 1290 | 0·5 | Changed to pseudowollastonite |
| 43 | 7 | 50 | 950 | 16 | Wollastonite |
| Previous charge reheated | | | 1328 | 45 | Wollastonite and trace diopside |
| Previous charge reheated | | | 1340 | 15 | Now partly pseudowollastonite |
| 41 | 8 | 51 | 950 | 15 | Wollastonite only |
| | | | 1340 | 0·5 | Recrystallized wollastonite and diopside |
| | | | 1345 | 0·5 | Recrystallized wollastonite and diopside |

[11] This interval of temperature will be discussed later.

These results indicate a considerable area of solid solution of wollastonite and that this area is probably even more extensive at low temperatures. The increased solubility of diopside at low temperatures has been previously noted by others.[12]

*The $5CaO.2MgO.6SiO_2$ Solid Solutions.*—The solid solutions which we have been discussing in nowise explain the wollastonite liquidus relations found by us and given in a previous paper.[13] These relations indicated the existence of two wollastonite fields, one corresponding to an optically positive and the other to an optically negative wollastonite. The latter, decomposing at about 1340°C, was evidently the solid solution of 17 per cent of diopside in wollastonite, but the former, stable below 1365°C, corresponded to nothing which we had then found existent in the ternary system.

Fortunately the finding of a maximum on the wollastonite-diopside boundary line (then so-called) enabled us to say that the composition of the solid solution inverting at 1365°C lay on a line which was an extrapolation of the line joining the diopside composition with the composition of the maximum on the boundary line. Now this line ran through the $5CaO.2MgO.6SiO_2$ composition, and therefore experiments were made in order to determine if a homogeneous product could be obtained in the region at and near this composition recorded in Table V.

TABLE V.

Experiments upon the $5CaO.2MgO.6SiO_2$ solid solutions.

| Composition wt. % | | | Temp. | Time in | Phases present |
|---|---|---|---|---|---|
| CaO | MgO | $SiO_2$ | °C. | hours | |
| 38 | 11 | 51 | 1360 | 0·5 | $5CaO.2MgO.6SiO_2$ + trace pseudo-wollastonite + a small quantity of glass |
| 38 | 12 | 50 | 1360 | 0·5 | Some glass + crystals |
| 39 | 11 | 50 | 1350 | 0·5 | A homogenous product[1] |
| | | | 1360 | 0·5 | Part decomposed into pseudo-wollastonite and glass |
| 42·4 | 8·8 | 48·8 | 900 | 15 | All wollastonite |
| | | | 1275 | 0·5 | Not decomposed |
| | | | 1300 | 0·5 | Not decomposed |
| | | | 1325 | 0·5 | Not decomposed |
| | | | 1345 | 0·5 | Barely started to decompose but clearly started |

[1] $5CaO.2MgO.6SiO_2$ would be CaO 38.9, MgO 11.1, $SiO_2$ 50.

[12] Allen, White, Wright, and Larsen, this Journal 27, 20, 1909.
[13] See fig. 1.

These results, taken in conjunction with the results obtained in the study of the fields corresponding to these solid solutions, which are given in the previous paper, make reasonably certain the existence of the compound $5CaO.2MgO.6SiO_2$, and of an area of solid solution which extends from this compound toward the calcium meta-

Fig. 2.

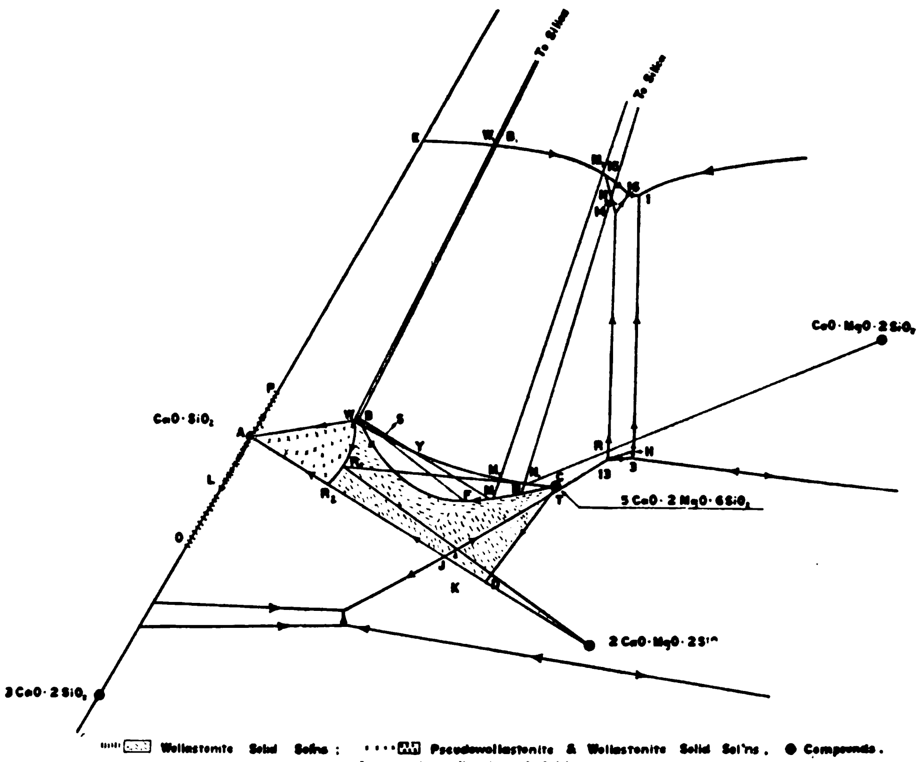



Fig. 2. The part of fig. 1 which deals with the calcium metasilicate and related solid solutions.

silicate-åkermanite line and joins with the area of wollastonite solid solutions. The compound $5CaO.2MgO.6SiO_2$ evidently does not form complete solid solutions with the wollastonite-diopside series of solid solutions. The linking together of the solid solutions of the diopside series and åkermanite with those of the åkermanite series and the compound $5CaO.2MgO.6SiO_2$ naturally results in the

formation of an area of solid solution having a minimum width intermediate between the 17 per cent diopside solution and the $5CaO.2MgO.6SiO_2$ composition. Since the decomposition temperatures of the solid solutions of the åkermanite series are but slightly above the inversion temperature of pure wollastonite and much less than the decomposition temperatures of either of the two solid solutions just mentioned, the decomposition temperatures of the solid solutions bounding the area running from the 17 per cent diopside solution to the $5CaO.2MgO.6SiO_2$ composition pass through a minimum at this point of minimum width (near F in fig. 2) and thus make possible the two fields of solid solutions which we found in the previous study.

*Solid Solutions with Åkermanite and $3CaO.2SiO_2$.*—The optical similarity and fibrous nature of some of the crystals found in charges with compositions lying within the region bounded by the wollastonite-åkermanite line and the wollastonite-$3CaO.2SiO_2$ part of the side line rendered any direct determination of homogeneity upon charges crystallized at low temperature impossible. An investigation of the inversion and decomposition temperatures within this region seemed also futile and therefore no definite results were obtained with such compositions. The only means available for determining if pseudowollastonite solutions extend across this region was a study of the temperatures of complete melting similar to that carried out upon the compositions between the diopside and åkermanite lines. Experiments were here not carried out as the liquidus relations previously obtained in no way indicated the existence of two pseudowollastonite fields. We think it probable that both the wollastonite and the pseudowollastonite solutions extend to the side line in this region.

## Discussion.

The liquidus-solidus relations of these various solid solutions were but briefly mentioned in the previous paper and a more thorough discussion will now be given. For this purpose, we have reproduced with a little more detail in fig. 2 that part of fig. 1 which dealt with these solid solutions, but omitting, because of the scale of the drawing, several minor parts[14] which would have to be

[14] Thus we show no solid solution of pseudowollastonite beyond the diopside line toward silica. (See p. 173.)

inserted if the diagram were exactly a representation of the facts as we have found them; also in those cases in which the results obtained were insufficient to indicate the exact relations we have chosen what appeared to us the most probable interpretation. Thus we show wollastonite taking up a little more diopside in solid solution than does pseudowollastonite, although our evidence is only sufficient to indicate that the limits lie close together.

The meaning of the symbols, etc., upon the diagram, is as follows:

| | | | | | | |
|---|---|---|---|---|---|---|
| AP | represents | the | solid | solutions | of | wollastonite and silica. |
| AO | " | " | " | " | " | wollastonite and $3CaO.2SiO_2$ |
| AL | " | " | " | " | " | pseudowollastonite and $3CaO.2SiO_2$ |
| AW | " | " | " | " | " | pseudowollastonite and diopside |
| AB | " | " | " | " | " | wollastonite and diopside |
| AD | " | " | " | " | " | wollastonite and åkermanite |
| $AR_2$ | " | " | " | " | " | pseudowollastonite and åkermanite |

The areas of solid solution are indicated by the shaded portions of the figure. The arrows show the directions of falling temperatures. The field, 14, 15, 16 corresponds to the solid solution B, the field 14, 16, 1, H, 13 to the solid solutions ranging from C to F, and the field 13, H, 3, to the solid solutions ranging from C to T. The locations of F and T are known only approximately. T may or may not be between C and the boundary 13J, and for simplicity we have placed it at the point of intersection of the boundary by CD. F is the solid solution stable at point 14, M the solid solution stable at 16, and N the solid solution stable at 1. C, the $5CaO.2MgO.6SiO_2$ compound, is stable along the line 13H, where H is the determined maximum on the line 1, 3. T is the solid solution stable at 3 and $R_1$ is the solid solution of pseudowollastonite stable at 13. $R_1$ is arbitrarily located and may or may not coincide with $R_2$. The pseudowollastonite solutions extend throughout the area $AWR_2$ and W may be in the position indicated or may coincide with B or be just on the other side of it. The decomposition temperatures of B and F are the same as the melting temperature of point 14, about 1340°C, and the decomposition temperature of C the same as the melting temperature of point 13. The latter has been the more carefully determined and is 1365°C.

With the aid of this diagram the products resulting from the crystallization during cooling *under equilibrium conditions* of the various compositions lying within the pseudowollastonite field may be worked out and the

results so obtained give one a clearer mental picture of the general liquidus-solidus relations than could otherwise be had. The last stages of the crystallization and the products are:

(1) Compositions lying within the region $AEW_1W$ crystallize along the line E15 and give mixtures of pseudowollastonite solid solutions of the series AW and silica.

(2) Compositions lying within the region $AWR_2$ crystallize to form pseudowollastonite solid solutions of their own composition.

(3) Compositions lying within the region $WW_1B_1B$ crystallize to mixtures of silica with the wollastonite solid solution B and the pseudowollastonite solid solution W;[15] the final glass has the composition of point 15.

(4) Compositions lying within the region $R_2R_1KJ$ crystallize along the line J13 to form mixtures of åkermanite with pseudowollastonite solid solutions of the series $R_2R_1$.

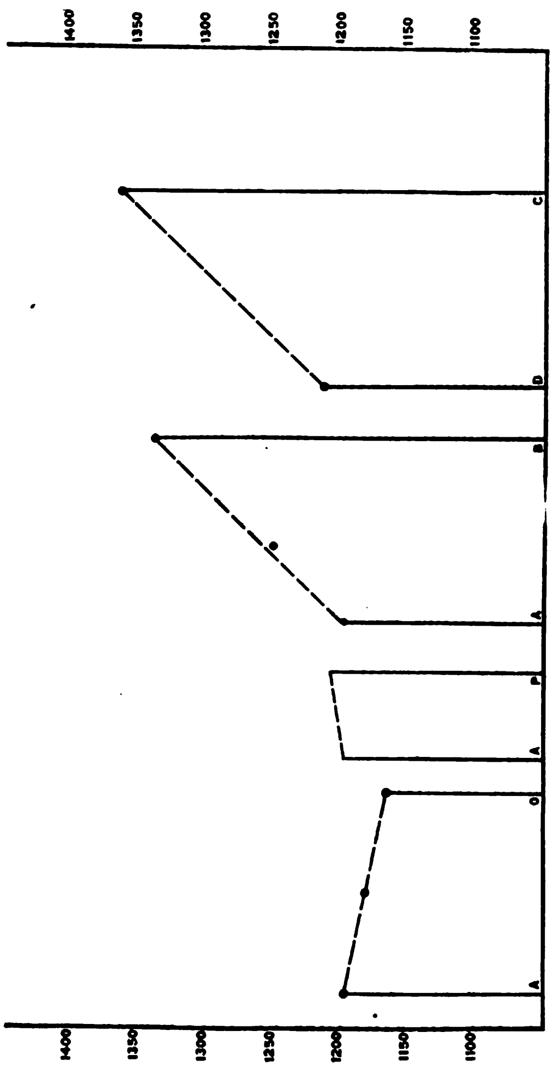
(5) Compositions lying within the region $R_1CTK$ crystallize to mixtures of åkermanite with $5CaO.2MgO.6SiO_2$ and the pseudowollastonite solid solution $R_1$; the final glass has the composition of point 13.

(6) Compositions which can go solid along the line 14, 13 will consist, when crystallized, of mixtures of solid solutions of pseudowollastonite of the $R_1W$ series and of solid solutions of $5CaO.2MgO.6SiO_2$ of the CF series; and the area representing these compositions is somewhat irregular in shape due to the fact that pseudowollastonite solid solutions change in composition from $R_1$ to W and the $5CaO.2MgO.6SiO_2$ solid solutions change in composition from C to F. These compositions will be represented by that part of the area which is covered by the lines joining the compositions of the two kinds of co-existing solutions which is not included in the area $R_1CTK$, namely, the area $R_1WC$. The lines joining the compositions of the two kinds of solid solutions which can co-exist are all tangents to WC which is somewhat curved.

(7) Compositions represented by the small area WBS will crystallize to mixtures of pseudowollastonite solid solution W, wollastonite solid solution B, and 5CaO.

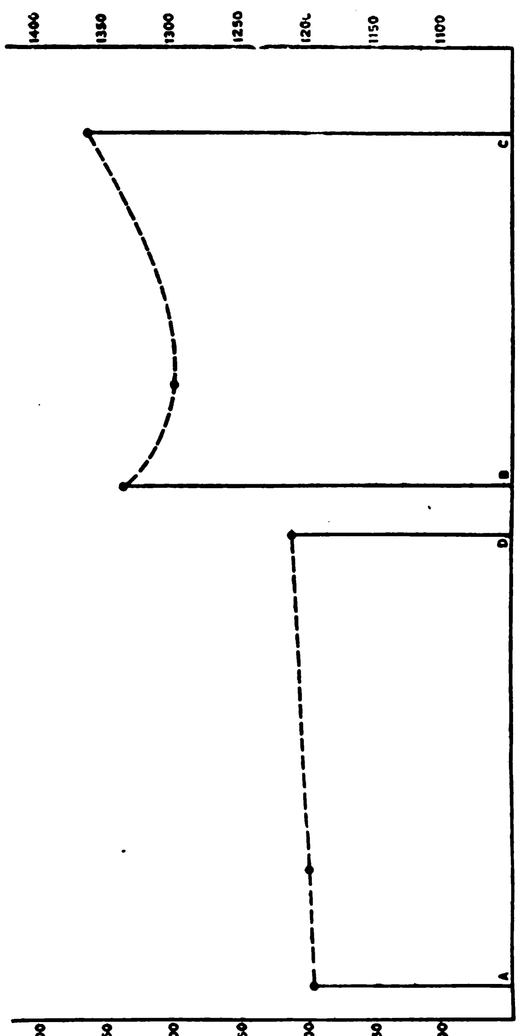
[15] The pseudowollastonite which crystallizes out along 14, 15 and at 15 contains a little more silica than solid solution W but these compositions lie too close to W to show upon the diagram (see footnote 14, page 177).

Fig. 3a.




Vertical projections which represent the general character of the inversion and decomposition temperature changes in the various series of solid solutions and in the solid solutions bordering the areas of solid solution.

FIG. 3*b*.




Vertical projections which represent the general character of the inversion and decomposition temperature changes in the various series of solid solutions and in the solid solutions bordering the areas of solid solution.

$2MgO.6SiO_2$ solid solution F; the final glass has the composition of point 14.

(8) Compositions represented by the area BSY will go solid along the line 14, 16 and form mixtures of the wollastonite solid solution B, and solid solutions of $5CaO.2MgO.6SiO_2$ ranging from F to M.

(9) Compositions lying within the region $BB_1M_2M_1Y$ will form mixtures of the wollastonite solid solution B, silica, and the $5CaO.2MgO.6SiO_2$ solid solution M; the final glass has the composition of the point 16.

(10) Compositions lying in the area $M_1M_2 15 N_2N_1$ will crystallize along the line 16, 1 to form mixtures of silica with solid solutions of $5CaO.2MgO.6SiO_2$ ranging from M to N.

(11) Compositions represented by the area $N_1N_2 14 R$ will crystallize to mixtures of silica, diopside, and the $5CaO.2MgO.6SiO_2$ solid solution N; the final glass has the composition represented by point 1.

(12) Compositions lying within the region $N_1R13TC$ will go solid along 1, 3 to form mixtures of solid solutions of $5CaO.2MgO.6SiO_2$ and diopside.[16]

Enough evidence to indicate the general character of the solidus relations has been presented. The inversion of pure wollastonite to pseudowollastonite has been found by previous investigators to take place at 1200°C and we have confirmed this figure upon the pure substances. The reverse reaction, i. e., the inversion of pseudowollastonite to wollastonite, we have never observed in the solid state except possibly in some charges which had been crystallized at 900°C and in which pseudowollastonite has first formed as an unstable phase and later partly inverted to wollastonite at somewhat higher temperature. Wollastonite solid solutions of the various kinds found by us in this system inverted with slight lags, but in none of these compositions could the reverse operation be induced to take place even by heat treatments of 16 or more hours. Perhaps the presence of large crystals of pseudowollastonite which form readily even in undercooled glasses is responsible for this sluggishness.

The melting interval of solid solutions is so well known

[16] Not strictly true as the area includes a small area which would crystallize at 13 to form mixtures of åkermanite, $5CaO.2MgO.6SiO_2$, and solid solution $R_1$ of pseudowollastonite but which lying near T is too small to show.

that comment here is unnecessary upon this point. Not so well known perhaps are the inversion intervals of solid solutions, the existence of which is demanded by the same theory that indicates the melting intervals. Thus the theory[17] predicts that the inversion temperatures in the case of complete solid solution between two components may pass through a maximum or a minimum or change gradually from the inversion temperature of the one component to that of the other, and that there will be a region represented upon a concentration-temperature diagram in which mixtures of the two solid solutions may exist at equilibrium. We have been unable to detect any inversion interval upon any of the compositions investigated. The segregation of the phases in the solid state is very slow, so that even if the resulting material does show some determinable crystals, still there may be doubt as to the interpretation of the structures seen. Furthermore, inversion is not rapid enough to show a temperature interval by purely thermal methods. Thus the methods are inadequate for the determination upon these charges of whether complete or only partial inversion has taken place although such intervals must exist. However, the theory does enable us to say that the inversion surface along the calcium silicate-diopside line is convex upwards.

If now we plot vertically upon figure 2 the inversion and decomposition temperatures,[18] given earlier in this paper, of the solid solutions which bound the area of solid solution and also those upon the side line and then make vertical projections of these we will obtain the curves given in fig. 3 which indicate approximately the effect of solid solution upon these temperatures. No great accuracy is claimed for these results, but their accuracy is sufficient to establish their general character. The direction and degree of the change in inversion temperature with solid solution in the various cases well illustrates the complexity of the phase relations and is in accord with the theory of such phase relations. These also emphasize the futility of the application to such cases

[17] It should be remembered that this theory assumes that the state of the system is completely determined by pressure, temperature and composition. If further experimental evidence indicates that the crystalline character of the substances concerned enters as an additional factor, some modification of the theory may become necessary.

[18] In reality the temperatures at which such inversions or decompositions begin, *i. e.*, the start of the inversion intervals for the various compositions.

FIG. 4.

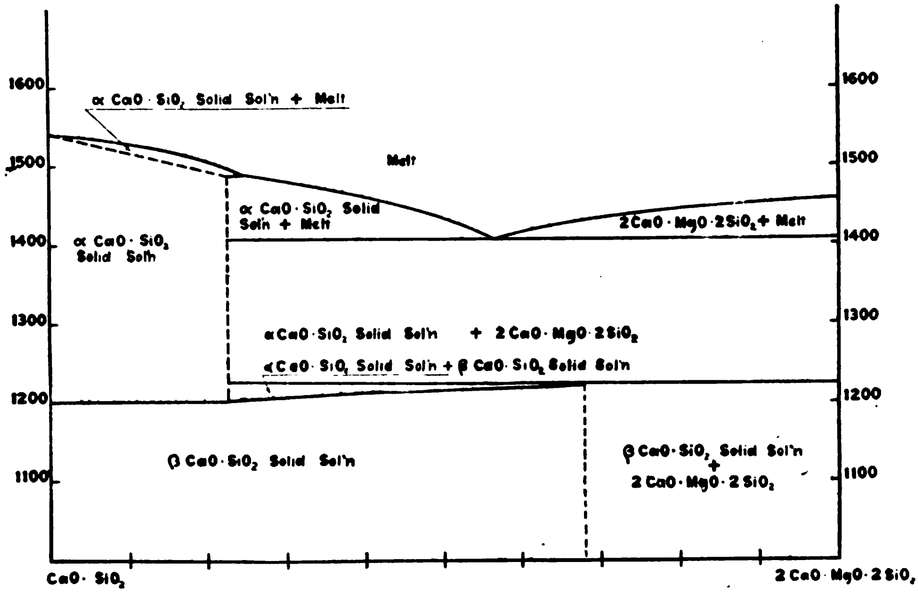



FIG. 4. The binary system $CaO.SiO_2$ — $2CaO.MgO.2SiO_2$.

FIG. 5.

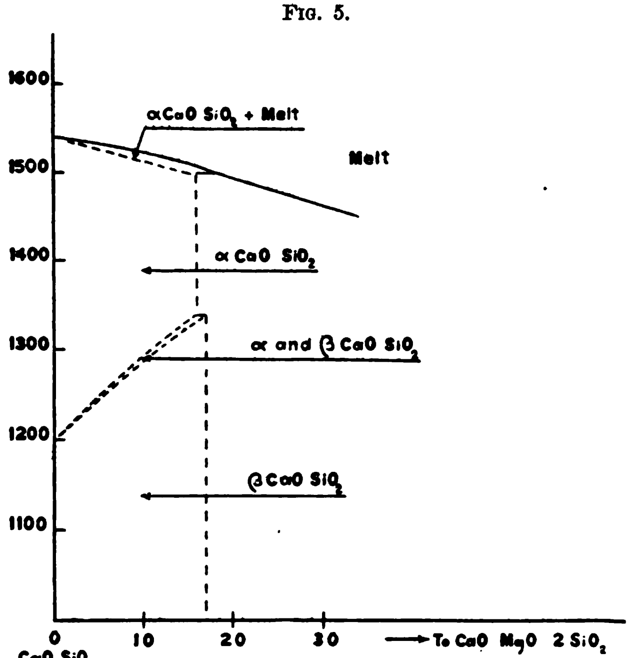



FIG. 5. The phase relations along that portion of the $CaO.SiO_2$ — CaO. $MgO.2SiO_2$ line which includes the wollastonite-diopside solid solutions.

of formulae derived by thermodynamical reasoning with the aid of the laws of dilute liquid solutions.[19]

The complete liquidus and solidus relations along the calcium metasilicate-åkermanite line, which forms a true binary system, are given in fig. 4. The calcium metasilicate-diopside line does not form a binary system and therefore only that part dealing with the solid solutions of the diopside series is given in fig. 5. The combined liquidus and solidus relations over the part of the ternary system which we have been discussing in this paper are depicted upon the model shown in figs. 6 and 7.

The compositions are indicated upon the base and the temperatures by the vertical distances above this base. The quintuple and quadruple points are represented by the black vertical wires and the boundaries of the fields by the black wires connecting these uprights. The solid solutions of $5CaO.2MgO.6SiO_2$ and of wollastonite are represented by the lighter-colored and lower portions of the solid part of the model, whereas the upper and darker portions represent the pseudowollastonite solid solutions. Fig. 6 is given to show the relation of the fields to the solid solutions and to the compounds calcium metasilicate and diopside. One can see at a glance that the latter compounds do not form a binary system. Fig. 7 is intended to give the reader an idea of the changes in the inversion and decomposition temperatures caused by solid solution. The inversion interval here shown between wollastonite and pseudowollastonite solutions was inserted upon theoretical grounds, no direct observation of it being possible with the methods available. The accuracy of our results is somewhat less than that suggested by these models.

*Unstable Phases.*—If we consider the value of the thermo-dynamical potential of a phase as a measure of its stability, then of all the possible phases, that phase which has the minimum potential will be the stable one. A system in passing from an unstable to a stable condition may change its potential in one step, or if phases of intermediate potential are possible, in several steps, and it is but natural to suppose that if several steps are possible the change will probably go by means of these steps. This simple conception in regard to the formation of unstable phases has been found of rather wide

[19] Ostwald, Lehrbuch der allgemeinen Chemie, Bd. 2, Teil 3, p. 70.

application. Little, however, has been done to show its applicability to silicate melts.[20] Attention is therefore called to the following definite observations which tend to show that the phenomenon is by no means rare in such melts and may be the rule rather than the exception.

(1) Allen, Wright and Clement[21] describe the forma-

FIG. 6.

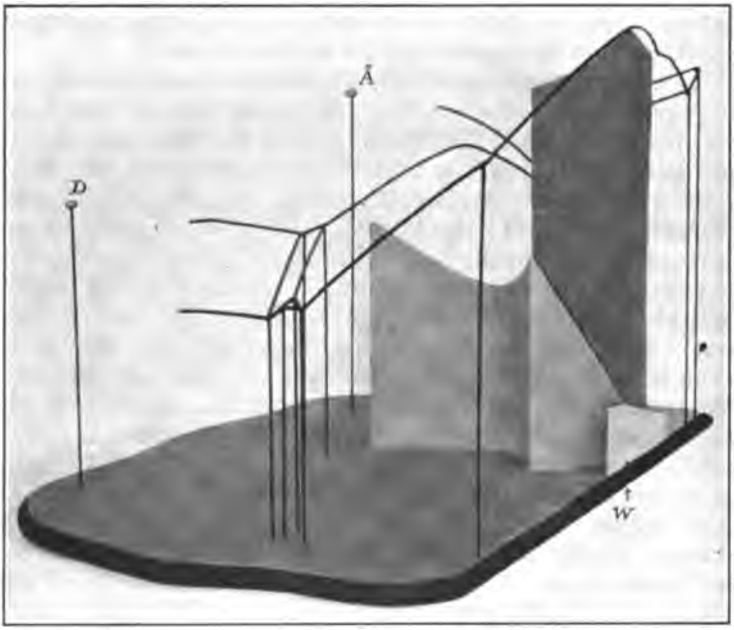



FIG. 6. A model representing the solidus and liquidus temperature-concentration relations in the part of the ternary system $CaO$-$MgO$-$SiO_2$ given in fig. 2. The dark upper portion represents the pseudowollastonite solid solutions; the lighter lower portion represents the wollastonite and $5CaO.2MgO.6SiO_2$ solid solutions; the black vertical wires with the connecting wires represent the fixed points and boundary curves; and the black vertical wires with light knobs at top represent the compounds åkermanite (A) and diopside (D). W = $CaO.SiO_2$, wollastonite and pseudowollastonite.

tion of an unstable fibrous magnesium silicate which forms from quickly cooled melts and which transforms into the stable clino-enstatite.

[20] Fenner (this Journal (4) **36**, 342, 1913), in his study of the forms of silica observed the formation of unstable phases in certain solutions somewhat resembling these melts and discussed Ostwald's law of successive reactions in relation to their formation.

[21] This Journal (4), **22**, 406, 1906.

(2) Rankin and Wright,[22] when attempting to synthesize the tricalcium silicate from the oxides, noted first the formation of the orthosilicate with a subsequent combination of this with lime to form the tricalcium silicate.

(3) Bowen[23] found that unstable carnegieite formed as an intermediate stage in the crystallization of nephelite from undercooled glasses when the temperature was not far below the decomposition temperature of the nephelite.

FIG. 7.

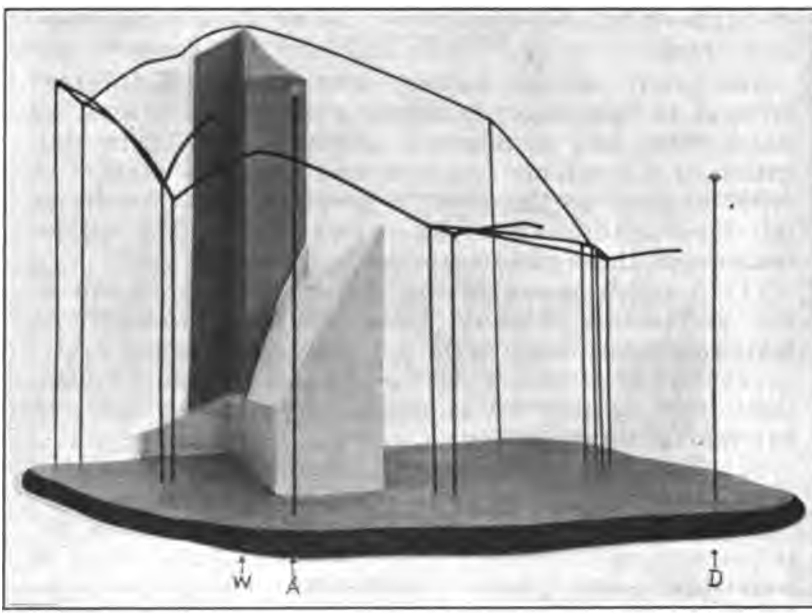



FIG. 7. A second view of the model given in fig. 6, intended especially to indicate the inversion and decomposition temperatures of the various solid solutions.

(4) Pure pseudowollastonite crystallizes readily from glasses of its own composition several hundred degrees below the temperature of its inversion to wollastonite.

(5) In cases in which a single low-temperature phase decomposes with increasing temperature to form two or more phases, we have found one or more of these phases initially present in charges of glass which had been crys-

[22] This Journal (4), 39, 8, 1915.
[23] This Journal (4), 33, 551, 1912.

tallized at temperatures below the temperature region at which these phases were stable. Thus we found pseudowollastonite in ternary compositions which should have been pure wollastonite or $5CaO.2MgO.6SiO_2$ solid solutions; binary compositions near the composition $3CaO.2SiO_2$ contained some calcium orthosilicate; and the ternary composition corresponding to the compound $CaO.MgO.SiO_2$ (monticellite) invariably gave not a pure homogeneous product but a mixture of a monticellite solid solution and calcium orthosilicate.

## Recapitulation.

The study of the ternary system $CaO-MgO-SiO_2$[24] brought to light many perplexing liquidus relations for which there was no adequate explanation. An investigation of the solidus relations was therefore started in order to clear up the doubtful points and the results of this investigation are given in this paper. The salient features of these results are:

(1) A confirmation of the earlier work in regard to the wollastonite-diopside solid solutions, wollastonite taking up a maximum of 17 per cent of diopside.

(2) The existence of solid solutions of pseudowollastonite and diopside containing as a maximum about 16 per cent of diopside.

(3) The finding of the new compound $5CaO.2MgO.6SiO_2$.

(4) The existence of solid solutions of åkermanite (or perhaps of an unstable compound $3CaO.MgO.3SiO_2$) in wollastonite and pseudowollastonite. The wollastonite solutions extend to a composition containing between 60 and 70 per cent of åkermanite, while the pseudowollastonite solutions extend to a composition containing about 23 per cent of the same compound.

(5) The presence of an area of solid solution which includes the wollastonite-diopside, the wollastonite-åkermanite, and the wollastonite-$5CaO.2MgO.6SiO_2$ solid solutions. The decomposition temperatures on this area between the 17 per cent diopside solid solution and the compound $5CaO.2MgO.6SiO_2$ pass through a minimum. $5CaO.2MgO.6SiO_2$ decomposes at 1365°C and the 17 per cent diopside solid solution at about 1340°C, while pure wollastonite inverts at 1200°C.

[24] This Journal, August number, 1919.

In addition to the results just mentioned, which suffice to clear up the liquidus relations in question, as thorough an investigation as the nature of the problem and the available methods of attack would permit was carried out upon the solid solutions of silica and $3CaO.2SiO_2$ in calcium metasilicate and upon the inversion and decomposition temperatures of all the various solid solutions.

A general discussion of these results with diagrams and models is given. The formation of unstable phases in silicate melts is also discussed, and the futility of attempting to use formulae derived from the theory of dilute solutions in order to calculate the change of inversion temperature with solid solution is briefly mentioned.

Geophysical Laboratory,
Carnegie Institution of Washington,
June 1, 1919.

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ART. XII.—*The Extent and Interpretation of the Hogshooter Gas Sand;*[1] by WALTER R. BERGER.

The Hogshooter gas sand is the producing horizon of the field of the same name. This field is about twelve miles in length, and from one to one and one-half miles in width, extending north from the west-central part of Township 24 North, Range 14 East, Washington County, Oklahoma.

The Hogshooter gas sand lies directly upon the Boone Formation, which is a cherty limestone of Mississippian age, underlying this region at a depth ranging from 1200 to 1400 feet. The sediments immediately above this sand in this locality, the Cherokee shale, are considered Pennsylvanian age. The sand varies greatly in thickness and pinches out at only a short distance to the east and west of the long axis of the field. The greatest thicknesses recorded in well records are near the center of the productive area. The maximum thickness recorded is 168 feet in well number 3 on the Taylor allotment in Section 18, Township 24 North, Range 14 East.

The sand horizon has been determined by means of several hundred records of wells drilled in this region, to

[1] Published by permission of Mr. Everett Carpenter, Chief Geologist, Empire Gas & Fuel Co.

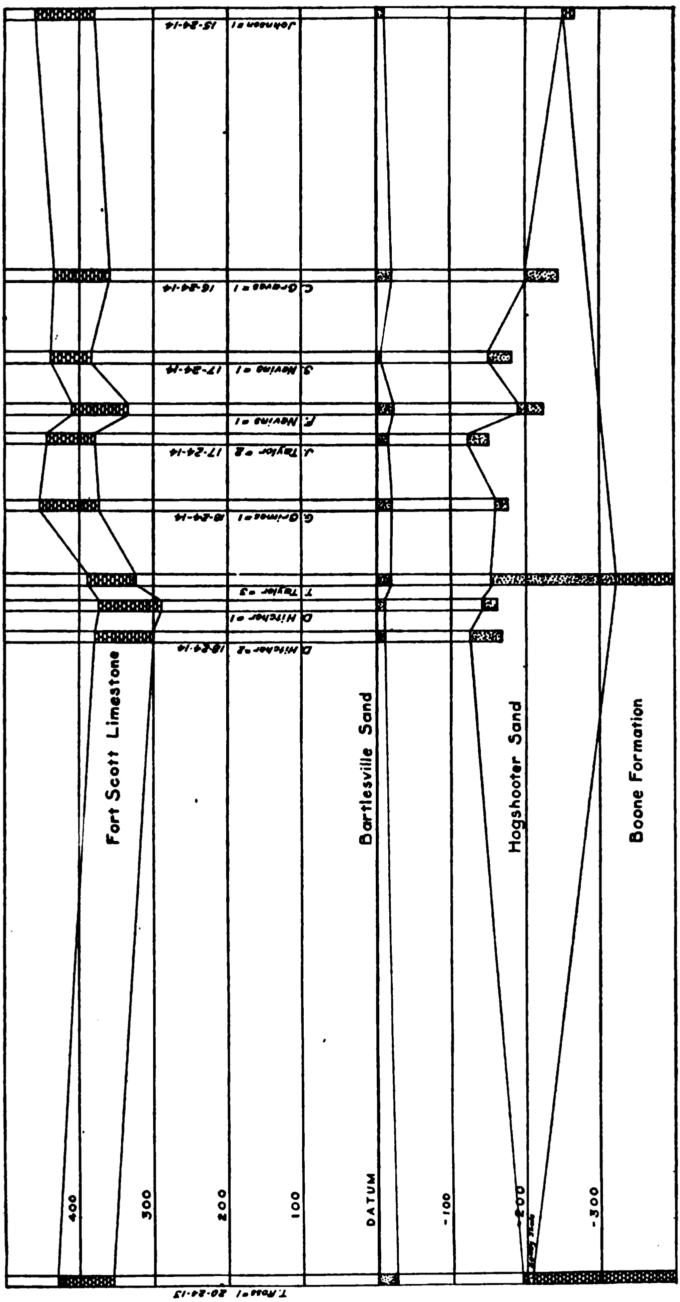
be a continuous body of sand in a north-south direction, but very narrow and lenticular in the opposite direction. To the north it is productive in the Burgess oil field, located at the corner of Townships 26 and 27 North, Ranges 13 and 14 East. The Burgess field extends in a southeast-northwest direction and is about four miles in length. North of this oil field the sand is productive of gas in scattered wells, and in the small gas field two miles east of Copan, Oklahoma. Five miles farther north, the Vander Pool produced from this sand. This field compares with the Hogshooter field in its shape which is long and narrow, extending northward from Section 34, Township 29 North, Range 13 East, into Kansas.

To the south of the Hogshooter gas field the sand is not so easily determined as it is to the north. This is due principally to two causes. Firstly, the reliable well records of this area are scarce. Secondly, the Cherokee shale and the Boone formation diverge[2] to the south and other beds come in between them. These intermediate beds thicken rapidly to the south, making it difficult to trace individual horizons in the well logs.

However, from the data available, it is considered that the Hogshooter sand takes an almost due south course. It is certainly the producing sand in the small oil field in the southwest corner of Township 23 North, Range 14 East. Six miles farther south a small gas field in Sections 35 and 36, Township 22 North, Range 13 East, and the oil field in the southwest corner of Township 22 North, Range 14 East, produce from this sand. The large gas field in the north central part of Township 21 North, Range 14 East, produces from a thick sand that seems to be the Hogshooter sand, even though the few good records show a thick shale to be present between the sand and the Boone formation.

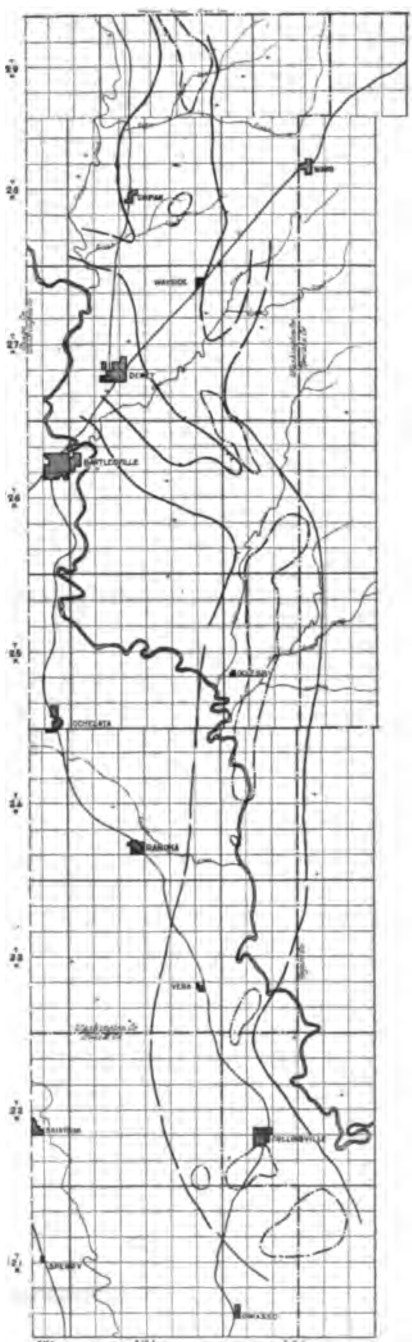
As before mentioned the Hogshooter sand is very narrow. Throughout most of its extent it varies from one to five miles in width. Locally there are narrow extensions westward and eastward from the main body. In the Hogshooter Gas field the sand has maximum recorded thickness of 168 feet, but does not appear in the logs of wells drilled four miles to the west and three miles to the east. In the Burgess oil field, where the axis

[2] Relation of the Ft. Scott Formation to the Boone chert of S.E. Kansas and N.E. Oklahoma, Journal of Geology, vol. 26, 7, p. 619.




East - West Cross Section

**HOGSHOOTER GAS FIELD**



**EXTENT OF HOGSHOOTER SAND**

Solid lines represent extent of sand.
Dashes represent outline of Oil or Gas Fields.
Crosses denote location of wells in which sand was not found.

extends nearly southeast-northwest, the thinning is even more rapid, from a thickness of at least 70 feet in wells near the center of the field to zero in wells one mile to the north and one-half mile to the south. Likewise in the Vander Pool the sand thins from about 100 feet to zero in one mile to the east and in but a little greater distance to the northwest.

The known locations of the eastward and westward extensions from the main body are as follows:

| | | | | |
|---|---|---|---|---|
| (1) | Section 32 and 33 | T. 28 N., R. 13 E. | Max. thickness | 34 ft. |
| (2) | " 32 | T. 27 N., R. 13 E. | " " | 17 " |
| | " 5 | T. 26 N., R. 13 E. | " " | |
| (3) | " 32 | T. 28 N., R. 14 E. | " " | 31 " |
| | " 17 | T. 27 N., R. 14 E. | " " | |
| (4) | " 32 | T. 24 N., R. 13 E. | " " | 42 " |
| | " 6 | T. 23 N., R. 13 E. | " " | |

There are probably other extensions which have not been shown by the drilling. This is especially true of the southern part of the area, but as previously stated the sands there cannot be readily traced.

Two wells have been drilled by the Empire Gas & Fuel Company, one in the Vander Pool and the other in the south end of the Hogshooter gas field, from which very complete sets of cuttings were taken. A study of these cuttings show that the Hogshooter gas sand is a light-colored sand, composed of rounded quartz grains, with a very small amount of muscovite, pyrite, and dark colored minerals. The size of the grains varies from 0·2 to 0·3 millimeters in the Hogshooter field, and from 0·3 to 0·6 millimeters in the Vander Pool.

All available data, especially the shape, thickness and irregular lenticularity of the sand in the east-west direction, lead to the conclusion that the Hogshooter gas sand must be the sand deposited by a large river along its course. This conclusion is strengthened by the fact that there was, at the time the sand was deposited, a topographical depression (which is interpreted as being an old river valley) in the area where the sand body is found. This depression extended north and northwestward as a trough which was present immediately prior to or during the early part of the deposition of the Cherokee shales. This topographical depression or trough is evidenced by the great thicknesses of the Cherokee shale

along this belt, in comparison with the thicknesses to the east and west. A stream coming from the region to the east of the granite hills of Kansas, which were undergoing erosion at this time, would come through this depression on its way to the pre-Cherokee basin, which lay to the south and east of the area under consideration.

The main body of the Hogshooter gas sand is interpreted as having been deposited in the channel of the principal stream flowing southward through the pre-Cherokee valley. The narrow and comparatively thin eastward and westward extensions of the Hogshooter sand are believed to be deposits made by tributary streams, in the lower part of their courses.

Similar deposits are known at the surface in central and northern Missouri, where two main channels have been mapped[3] as the Warrensburg and Moberly Channels. These channels and their tributaries were made by streams flowing to the north and west from the old land mass in southeast and central Missouri. These channels were formed considerably later in Pennsylvanian time than the deposit just described, and at the time of their formation, the depositional basin had expanded far to the northward and westward.

The writer is indebted to Mr. A. W. McCoy, under whose direction the work has been carried on, and also to Dr. L. C. Snider, for valuable suggestions.

[3] Missouri Bureau of Geology and Mines, 2d Series, vol. 12, pp. 91-106.

ART. XIII.—*Abnormal Birefringence of Torbenite;* by N. L. BOWEN.

In checking over the properties of an unknown mineral it was found that they agreed in general with those given for torbernite, except in the case of the optical properties. Torbernite, or copper uranite, is described as uniaxial and negative with indices 1·592 and 1·582. It should, therefore, have a reasonably high birefringence. The unknown mineral had a mean index of about 1·62 and very weak positive birefringence, at least it appeared positive in white light. At first, it was thought the mineral could not be torbernite but examination of two labeled torbernites in the University collection, one from Cornwall and one from Spain, revealed the fact that they corresponded exactly with the unknown mineral. It was then found that Rinne had studied the dehydration of torbernite or copper uranite and had described the series of so-called "Metakupferuranite" so obtained. One of these, representing the first step in the dehydration, is described as uniaxial and positive with very weak birefringence.[1] Later Buchholz determined the nature of the change represented by this first step and found it corresponded with a loss of 4 molecules of water, a change from 12 $H_2O$ to 8 $H_2O$.[2] He ascribed the fact that most analyses of torbernite have yielded only 8 molecules of water to the keeping of the material in a desiccator before analysis. Though Rinne gives no details of the properties of the optically positive variety of torbernite it would appear that the present torbernites correspond entirely with his and, therefore, that the first step in the loss of water may take place spontaneously on exposure. The specimens here described were not dried in any way, whether in a desiccator or by heating to mount them in Canada balsam. It is probably to this spontaneous loss that the common finding of only 8 molecules of water is to be attributed.

The torbernites were studied merely by crushing them and examining the powder in immersion liquids under the microscope. On account of the highly eminent basal cleavage most of the grains so obtained represent basal

[1] Centralblatt Min., 1901, p. 623.
[2] Centralblatt Min., 1903, p. 364.

sections and in parallel light they are absolutely isotropic. In convergent light very thick plates are uniaxial and appear to be optically positive for white light. The prismatic cleavage is sufficiently good so that occasional grains represent prismatic sections though always elongated parallel to the base and in these the relative values of the two indices compared with that of the liquid show that the index of the ordinary ray is the lesser for white light. The interference colors, are however, very abnormal. There is no suggestion of the normal succession of colors as the grains increase in thickness. The color of all the grains is not far from that of a sensitive tint plate, though it is sometimes the

Fig. 1.

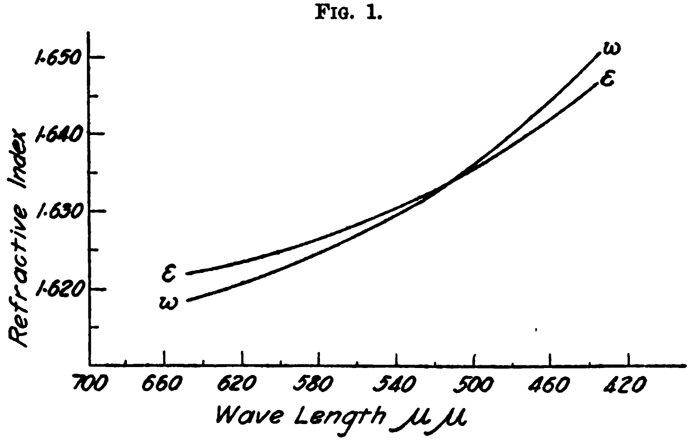



Fig. 1.—Refraction indices of "torbernite" from Cornwall.

blue of an overthick plate and again the red of a thin plate. It was suspected, therefore, that the mineral was isotropic for a color in the middle of the spectrum and a detailed measurement of the indices for various colors was undertaken. This was done in immersion liquids under the microscope and a monochromator was used as a light source. The indices of the liquids for various colors was known, and, therefore, their dispersion curves also, so that it was only necessary to find the wave-lengths for which the index matched three or four adjacent liquids and repeat the determinations for each ray. In this manner, it was found that the mineral was positive for the red end of the spectrum, negative for the blue end and isotropic in the green at about 515$\mu\mu$. The

exact results are given graphically in fig. 1. The wave-length for which there is no difference in the index of the two rays was checked—it was, indeed, fixed with somewhat greater accuracy—by examining the interference of prismatic sections. As the drum of the monochromator is turned and light of various colors passes through the sections, they remain brightly illuminated through the red and yellow; then rather abruptly in the green, at 515$\mu\mu$, they become dark and finally as the drum is turned farther they brighten up in the blue, in this case not so abruptly. It will be noted that the dispersion of the ordinary ray is greater than that of the extraordinary.

By reference to the ordinary diagram used to illustrate

FIG. 2.

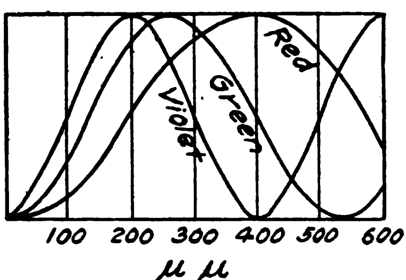



FIG. 2.—Showing the manner in which colors combine to give "interference color" for various values of retardation.

the interference color of thin sections, an explanation of the abnormal colors of torbernite is readily obtained. Such a diagram is given in fig. 2, where the wave-lengths for three colors are plotted and the color of a section is determined by noting the proportion in which the colors combine for any given value of the retardation. Thus, with a retardation of about 250$\mu\mu$, the violet, green and red are combined in about the proportion in which they are contained in the original light source and, therefore, white light is reproduced. The diagram is based on the assumption that the retardation is the same for all colors, which is never strictly true and in extreme cases, such as the present, may be far from the truth. For torbernite the retardation is always zero in the green and is very small for adjacent colors. An approximation to the interference color of torbernite sections may be

deduced from the same diagram by neglecting the green. Thus, assuming approximate equality in the retardation for red and violet by a given section, the interference color corresponding to a retardation of 250$\mu\mu$ will be one containing red and violet in equal amounts and as the dominant colors. The color of the section will, therefore, be practically that of the sensitive-tint plate; thinner sections will be bluer, and thicker sections redder. At a retardation of about 400$\mu\mu$ the color will be nearly a pure red and as the section thickens this will become bluer until at about 530$\mu\mu$, a color close to the sensitive tint will be observed again. This corresponds rather closely with the real sensitive tint, for this is the point at which green is cut out even in a mineral with normal birefringence. At this point the color becomes bluer as the section thickens and redder as it thins as with the normal sensitive tint. It is readily seen, then, why the interference colors of the grains, seen under the microscope, are always a red, blue or purple and are quite conspicuous even in thin grains that with normal birefringence would give only inconspicuous grays. It is a mistake to state that the interference color is always the simple complementary color of that for which the mineral is isotropic.

I am indebted to Dr. H. E. Merwin of the Geophysical Laboratory for the use of a monochromator and for information regarding the dispersion of the liquids used.

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ART. XIV.—*Organic Structures in the Biwabik Iron-bearing Formation of the Huronian in Minnesota;*[1] by FRANK F. GROUT and T. M. BRODERICK.

The emphasis recently given[2] to structures attributed to algæ and other organisms in pre-Cambrian rocks may make it desirable to record, in more detail than has been done, the structures that occur in the Upper Huronian (Animikie) rocks of the Mesabi range in Minnesota. The Biwabik iron-bearing formation extends along the range for nearly 100 miles, and throughout the east half, recently studied by the Geological and Natural History Survey of Minnesota, the outcrops and drill cores show structures closely resembling those now attributed to algæ. They will probably be found to extend over the whole range. The engineers of the Oliver Mining Company mention them as "contorted beds" in reporting the character of drill cores. Leith has shown[3] in a colored plate in the monograph on the Mesabi district, a fair sample of the red banded cherts, but suggests that their contorted nature may be due to movement.

*The Biwabik Formation.*

The formation as a whole is from 400 to 800 feet thick, and though all parts of it are called taconite, a number of divisions are recognizable. In the eastern end of the range the lowest member is about 20 feet thick, and consists largely of a chert with coarse wavy bands (fig. 1). Above these basal members of the formation is a black slate grading upward into a slaty chert. Above this is taconite with the texture of an intraformational conglomerate. Throughout the eastern area where outcrops are numerous, the conglomerate makes a bed about 100 feet thick and is noteworthy for the abundance of magnetite it contains. About 10 feet below the top of this

[1] Published by permission of the Director of the Minnesota Geological Survey.

[2] Walcott, Charles D.: Pre-Cambrian Algonkian algal flora, Smiths. Misc. Coll., 64, No. 2, 111, 1914.

*Idem*: Notes on fossils from limestone of Steeprock series, Ontario, Geol. Survey Canada, Mem. 28, 16, 1912.

Moore, E. S.: The iron-formation on Belcher Islands, Hudson Bay, etc. Jour. Geology, 26, 412, 1918.

Schuchert, Charles: A Text-book of Geology, Pt. II, Historical geology, 570-575, 1915.

[3] Leith, C. K.: The Mesabi iron-bearing district of Minnesota, U. S. Geol. Survey, Mon. 43, Pl. XII A.

conglomerate bed is a second zone, a few feet thick, of cherts with the structures of much smaller size, supposed to be organic. In nearly every outcrop of the chert, a bed several inches thick can be followed for several yards, with the organic structures as abundant as they are shown in figs. 2 and 3. There are commonly finger-like masses, such as are shown by Leith's plate.[4] Above the conglomerate is thin-bedded taconite to the top of the formation. The two beds, one near the base of the for-

FIG. 1.

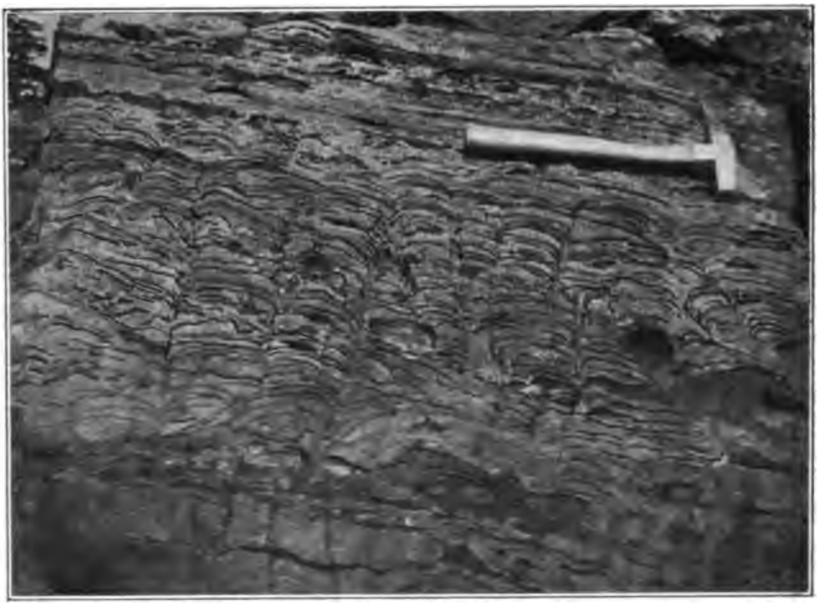

FIG. 1. Skeleton photograph of a vertical section of lower algal beds; Biwabik formation.

mation, and one near the top of the cherty conglomerate, are remarkably persistent, and show an abundance of the organic structures throughout. The chert is hard and outcrops in many places.

*Mineral Composition of the Organic Forms.*

These rocks showing structures attributed to organisms are made up of ferruginous chert. Most of the drill

[4] Leith's description says the forms are characteristic of the basal horizon, but the basal beds are usually much coarser than the one illustrated, whereas the upper bed is in most places much like the specimen he shows.

cores show a minute banding in red and white bands. The outcrops at the east end of the range show some beds of the same red color, but over large areas the color has been changed to gray, apparently by the alteration of hematite to magnetite. The iron oxide in the chert consists of scattered grains, arranged so as to produce the banded appearance.

Associated beds carry quartz, amphibole, and magnetite as predominant constituents, with many other minerals in small amounts. The occurrence of carbonates

FIG. 2.

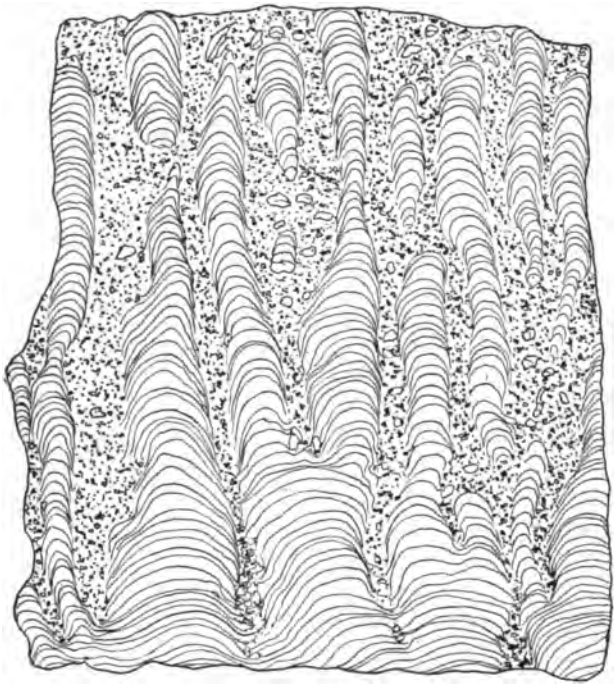

FIG. 2. Sketch of smooth vertical cross section through the upper algal beds (natural size), Biwabik formation.

and graphite may be in some way related to the organisms giving structure to the chert, but the detail of that relation is not clear, for neither mineral has been detected in the cherts that show the best structures. The graphite, however, probably indicates that the conditions of accumulation of most of the formation were not unfavorable to organic growth.

It is noteworthy that the structures appear in the Mesabi range mostly in ferruginous cherts. Most of the algal and similar organic structures in pre-Cambrian rocks, so far described, are in carbonate rock. It might be suggested that the original carbonate has in this case been replaced by chert, but the lack of any remnant of compact carbonate is opposed to the suggestion. The carbonate found in associated beds is disseminated and not apparently the remnant of a bed that was highly cal-

FIG. 3.

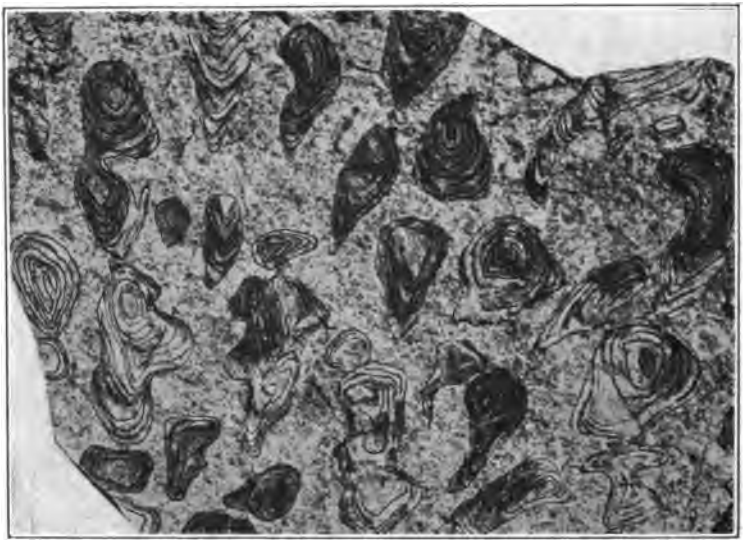

FIG. 3. Sketch in photograph of horizontal section through upper algal beds (natural size); Biwabik formation.

careous. Furthermore, there is no reason to expect early forms to be so uniformly calcareous as recent forms. And even recent organic precipitates include some that are siliceous and some that are ferruginous. Clarke has argued that the early forms were probably dominantly siliceous.[5]

*Forms and Structures.*

The structures and forms in the two beds are so different that they require separate description. The average

[5] Clarke, F. W.: Geochemical evidence as to the early forms of life. Jour. Wash. Acad. Sci., 6, 603, 1916.

appearance of the lower cherts is shown in figure 1, in which the lines of a photograph are emphasized by drawing. The structures differ markedly from algal forms as described from some other formations, in not being concentric and hemispherical. They show a marked tendency to develop columns, with a structure like a pile of similar inverted bowls. The higher bowls may be larger or smaller than the lower, but probably start at the bottom of the pile with a small dome and concentric structures. It seems likely that many small centers of growth developed hemispherical forms till they interfered with each other, and then developed by successive layers on the top, with more or less interference laterally from their neighbors. This interference may in the average case practically merge the layers of adjoining columns into a single undulating layer, gently convex on the domes, and sharply concave between. The columns range from two inches to two feet in diameter. At certain places on the undulating surface new centers may start and interrupt the regularity of the columns and bands.

The upper zone shows no such coarse structure and should apparently be attributed to a different species; in detail it shows much clearer, more distinct columns. Resting between thick beds of highly ferruginous intraformational conglomerate, the bed of chert is in sharp contrast with its surroundings. However, near the cherty beds the conglomerate contains numerous fragments of chert, and it is evident that the organic growth, though extending continuously many miles, does not indicate any radical change of conditions from those of conglomerate formation.

In the best exposures, the organic forms resemble finger-like columns, with a structure that may be described as that of a pile of thimbles. In diameter the columns are about like fingers and may be scattered an inch or more apart, though usually much closer. They stand much more distinct from their neighbors than the larger columns of the lower horizon. The spaces around each column are filled with granular matter and pebbles exactly like those of the conglomerate. The bands of iron oxide in chert, which mark the conspicuous structure, do not run out in most cases among the fragmental grains; but enough cases have been discovered where they do run among the pebbles, and even around them

concentrically, so that it is clear that the precipitation and deposition of fragments were about simultaneous. Leith notes[6] that under the microscope the shapes of granules can be seen to have been retained by the chert

FIG. 4.

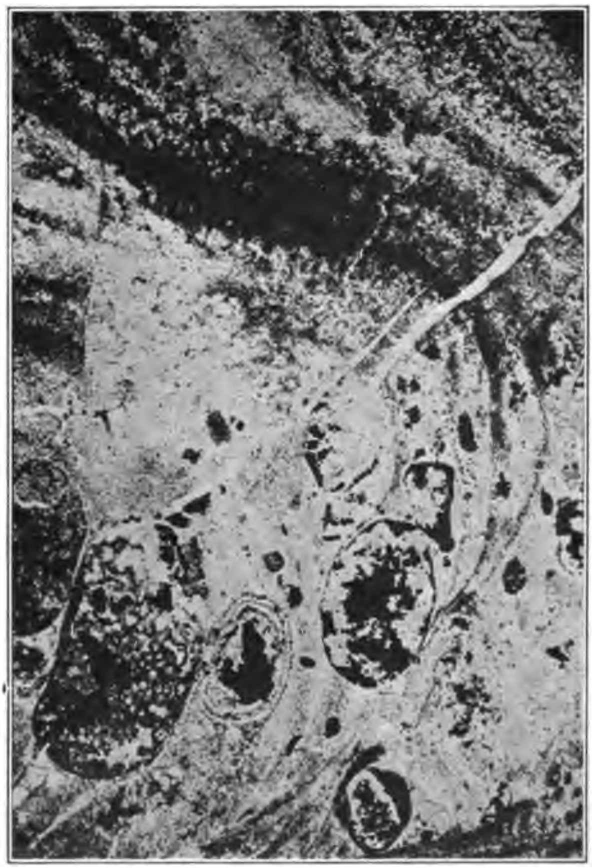

FIG. 4. Algal structures magnified ($\times 30$). The bands marked by iron oxides are mostly convex upwards, but some connect across the granular spaces and even run around granules concentrically.

and iron oxide. This no doubt refers to greenalite granules which are altered to chert and iron oxide. Quite aside from this alteration effect, however, there is clear indication of precipitation of chert in concentric layers around some fragmental granules.

Microscopic examination revealed no cell structures in the cherts. Recrystallization of the cherts has probably

[6] Loc. cit.

advanced too far to leave any such structures. The thin sections show crystalline iron oxides scattered in rough lines across the fine-grained chert. (Fig. 4.)

*Conditions of Deposition.*

Van Hise and Leith have argued that the Biwabik formation was deposited in shallow water.[7] This is clearly indicated by the flat forms of the pebbles in the intraformational conglomerate. They find further evidence in the dominance of quartz over carbonates, the structural differences between the Mesabi and Cuyuna ranges, and the lack of outcrops farther north. These shallow-water conditions are those that at the present day favor algal growth and deposition.

*Nature of the Organisms.*

The classification of the organisms producing the structures is a matter of less certainty. Specimens were submitted to Dr. Walcott, who wrote us as follows:

"The structure shown in the specimens is very much like that which occurs in the siliceous limestones of the pre-Cambrian in the Grand Canyon, Arizona, and somewhat like those found in the pre-Cambrian Belt series of Montana. The Grand Canyon forms are referred to *Collenia.* I am at a loss to explain the origin of such structure without the influence of some organic agency acting in conjunction with diffusion and concretionary phenomena."

Samples were also sent to Dr. Charles Schuchert, who wrote in description:

"If I had gotten such structures in any Ordovician limestone I would have called them algæ related to *Cryptozoon.* In Newfoundland I got not only regulation *Cryptozoon,* but, as well, thin finger-like or pipe-like bushy forms. Evidently the iron was segregated out of the marine waters through the metabolism of the algal growths, and it is surprising to see how it is laid down in thin concentric bands."

If the forms are referred to *Collenia*(?), the lower, more columnar ones may be given the specific name *biwabikensis,* from their occurrence near the base of the Biwabik formation, while the specific name *ferrata* for the smaller, upper beds may be an appropriate reference to the iron content of the chert.

University of Minnesota.

[7] Van Hise, C. R., and Leith, C. K.: The Geology of the Lake Superior region. U. S. Geol. Survey, Mon. 52, 214, 604, and 613, 1911.

ART. XV.—*Notes on an Unlisted Mineral;* by GEORGE J. HOUGH.

In 1901 there was found in a famous old mine in Mexico, a small amount of an unknown silver-copper mineral; I made reference to the discovery of this mineral in a descriptive article on Mexican Mines, published in the *Mining and Scientific Press* in 1911, but did not describe it in detail. The mineral was found in the Cocinera Mine of the Mexican Copper Company, at Ramos in the State of San Luis Potosi; a place famous in the old colonial days of Mexico as a silver producer.

The ore body in this mine, from the earliest times, was largely composed of heavy copper sulphide minerals, notably bornite and tetrahedrite; but at a depth of 1100 feet a great pocket of oxidized ore was met with, containing the red and black oxides of copper, some carbonates, and some metallic copper and metallic silver; and it was in this oxidized ore that the new mineral was encountered. It was not at first recognized as a new mineral, and consequently only a few pieces were saved for investigation, the total amount mined probably not exceeding several pounds.

The mineral has the appearance of an alloy, silver-gray in color with a metallic luster, and slowly tarnishes black; the streak is lead gray, the hardness 2·5, and the specific gravity 6·14; under the microscope it is seen to be homogeneous. It was found only in a massive form.

Careful analyses on the purest obtainable samples were made by the writer, at that time assayer and chemist for the Mexican Copper Company; these analyses gave the following composition: Copper 60·58%, silver 27·54%, iron 1·55%, sulphur 9·65%; the iron is probably an impurity often found as a replacement in copper sulphide minerals.

The empirical formula from this analysis is $Cu_4AgS$, which corresponds to no known mineral species, though from its similarity to stromeyerite $(AgCu)_2S$ it might be a variety of that mineral. As an appropriate name for this apparently new mineral, I would suggest *Cocinerite.*

**Bureau of Soils, Department of Agriculture,
Washington, D. C.**

**Art. XVI.**—*Note on the Depth of the Champlain Submergence Along the Maine Coast;* by Philip W. Meserve.

It has been noted frequently that a submergence to a depth of about 200 feet took place along the coast of Maine during the Champlain period. Raised sea beaches are found along the coast on the seaward flanks of low hills such as Black Strap Hill and Poplar Hill, a few

Fig. 1.

Fig. 1. Champlain Sea-cave, Mt. Ararat, Topsham, Maine.

miles northeast of Portland, Maine[1,2] and fossil-bearing marine clays are found widely distributed along the coast at a height not greater than 100 feet.[2]

The depth of the Champlain submergence can not be told exactly from the height of the raised sea beaches, for subsequent erosion has frequently removed or remodeled the sands and gravels of the beach crests. For this reason, the author desires to place on record a

[1] W. M. Davis, Physiography of the Coastal Plain of Maine, in the "Guide to the Vicinity of Boston," Fiftieth Anniversary Meeting of A. A. A. S., 1898, p. 5.

[2] George H. Stone, Glacial Gravels of Maine, U. S. G. S. Monograph, vol. 34, pp. 49-59.

brief description of what he believes to be a sea-cave, formed during the Champlain period. This cave is located on the southeast slope of Mount Ararat, a hill 255 feet high in the town of Topsham, Maine, mapped on the Bath sheet, U. S. G. S. Topographic Atlas. As measured several times by an aneroid, this cave stands 216 feet above the present sea-level. The mouth of the cave is about four feet in diameter; the cave extends horizontally into the rock for a distance of about fifteen feet. The rock of Mount Ararat consists chiefly of highly metamorphosed quartzites and quartz-schists, with associated pegmatites.

In view of the fact that there is good evidence for the former submergence of portions of the coast of Maine to a depth of about 200 feet, it appears quite probable that this cave was eroded by wave action. Two hundred and sixteen feet can be assigned, then, as the depth of the Champlain submergence in the Casco Bay region of the Maine coast.

Bowdoin College,
Brunswick, Maine.

ART. XVII.—*On the Correlation of Porto Rican Tertiary Formations with other Antillean and Mainland Horizons*;* by CARLOTTA JOAQUINA MAURY.

## REVIEW OF PREVIOUS WORK.

Professor Charles P. Berkey in his "Geological Reconnoissance of Porto Rico,"[1] March 1915, differentiated the formations of the island into the Younger Series including the Tertiary to Recent, and the Older Series constituting a very complex Pre-Tertiary group. It is with the Younger Series only that this paper is concerned. Provisionally, Dr. Berkey subdivided[2] the Younger Series into: (1) the San Juan formation, composed of Pleistocene sand dunes, and (2) the Arecibo formation of limestones with associated shales and marls. As phases of the Arecibo formation he mentioned the San Sebastian, or Lares shales, the Juana Diaz marls and the Ponce chalk beds. Regarding the age Dr. Berkey remarked:[3] "The Arecibo formation is of Tertiary age. So far as identifications of the fossils have gone, they appear to confirm the opinion that the larger part of the formation belongs to the Oligocene epoch. These determinations were based largely on collections made in the heavy limestone beds and reefs in the vicinity of the Quebradillas River. The shale beds lying at the base of the series, and exposed farther to the south in the vicinity of Lares, are certainly somewhat older and probably belong to the Eocene epoch. There are higher beds developed rather irregularly that doubtless represent still later time, referred by R. T. Hill to the Miocene epoch, but these determinations must be left to future detailed study of the formation as a whole."

In June and July of 1915, Dr. Chester A. Reeds, assisted by Mr. P. B. Hill, made a collection of invertebrate fossils from Porto Rico under the auspices of the New York Academy of Sciences and the Porto Rican Government, the American Museum of Natural History coöperating. It is with the molluscs of this collection that this summary report deals. Dr. Reeds, in a paper pre-

* Published by permission of the Director of the American Museum of Natural History.

[1] Ann. New York Acad. Sci., 26, pp. 1-70, Pl. I-III, 1915.

[2] *Op. cit.*, p. 10.

[3] *Op. cit.*, p. 61.

sented before the Geological Society of America, in 1915, on "Stages in the Geological History of Porto Rico,"[4] remarked that the majority of the fossils collected by him in Porto Rico were gathered from the lignitic shales and white limestone of the Younger Series. Only a very brief examination had been made by Dr. Reeds of his collection, but he noted that the sea urchins indicated a "late Eocene or Early Oligocene age."

In the discussion following Dr. Reeds's paper, Mr. Edwin T. Hodge said that he found on Sierra Cayey a coral characteristic of the Edwards formation of the Gulf, and some miles farther south, "the lower portion of a *Venericardia alticosta* index for the Chickasawan and Claibornian of the Gulf." Hodge stated that the Cretaceous and Eocene strata in which these fossils were found had been peneplained and the later limestones deposited upon this peneplain. From fossils collected by Dr. Berkey and studied by Dr. Marjorie O'Connell, Hodge said that we knew the later limestones to be of Oligocene age.

Dr. Reeds in a paper on "Porto Rican Localities Yielding Vertebrate Fossils"[5] described finding remains near San Sebastian and Juana Diaz. He separated the San Sebastian and the Juana Diaz shales from the Arecibo formation, and applied the name Collazo shales to the former, because of their typical occurrence on Rio Collazo.

Dr. W. D. Matthew identified one of the vertebrate fossils from the Juana Diaz shales, as the jaw of the European Oligocene and Miocene Sirenian genus *Halitherium* and described it as *H. antillense*.[6]

Mr. D. R. Semmes[7] referred the Arecibo limestone to the Upper Oligocene and the San Sebastian shale to the Lower Oligocene.

Dr. Anna I. Jonas made preliminary identifications of the Porto Rican collection at the American Museum referring many of the mollusca to Claibornian and Jacksonian species.[8] Her identifications are, unfortunately, exceedingly erroneous. She lists twenty-one of those identified as Gulf State Eocene and twenty as Gulf State Oligocene species, but refers none to any Antillean fossil

[4] Bull. Geol. Soc. Amer., 27, p. 84, 1916.
[5] Ann. New York Acad. Sci., 26, p. 437, 1915.
[6] *Op. cit.*, p. 439; and 27, pp. 23-29, 1916.
[7] Ann. New York Acad. Sci., 27, p. 279, 1917.
[8] Ann. New York Acad. Sci., 27, p. 281, 1917.

species. Dr. Jonas concluded that the Arecibo limestone "is both Upper Eocene and basal Oliogcene and the Collazo shale is Upper Eocene."

In 1917, after making an expedition to northwestern Santo Domingo and working up the fossils collected there, but without having seen any from Porto Rico, I suggested that[9] "The Lares shales *may* go with the *Orthaulax* zone of the Yaqui Valley, or perhaps with the probably older Monte Cristi range. The limestones and marls above the Lares shales perhaps correspond to our *Aphera* and *Sconsia* formations."

Dr. Vaughan of the U. S. Geological Survey, in his 1919 Correlation table of the Formations of the Canal Zone with those of the West Indies and Central America,[10] gives but one horizon in Porto Rico, the Pepino formation, which he correlates with the Antigua formation, and with the Lower Culebra of Panama.

## Conclusions based on a Study of the Fossil Mollusca.

All the preceding statements, or prophecies, regarding the Tertiary stratigraphy of Porto Rico were chiefly based on structural and physiographic relations, since only a very preliminary study of the fossil faunas had been made by any of the authors quoted.

The American Museum of Natural History this Spring requested me to make a critical study of the fossil mollusca collected in Porto Rico by Dr. Reeds in 1915. The discussion of the species will be published later, but it is hoped that the following brief résumé of the faunas and their stratigraphic relationship may be deemed of interest.

I wish to thank Dr. Lucas, Director of the American Museum, Dr. Hovey, Curator of the Geological Department of the Museum, and Dr. Berkey, Geologist of the Porto Rican Committee of the New York Academy of Sciences, for their very kind permission to publish this summary in advance. Acknowledgment is due likewise to Dr. Reeds, Associate Curator of Invertebrate Paleontology at the Museum, for helpful information regarding field relations of the fossils studied.

[9] Bull. Amer. Paleontology, No. 30, p. 42.
[10] U. S. Nat. Mus., Bull. 103, opposite p. 595, 1919.

### *Faunal Groups Represented.*

(1) The first faunal group differentiated was that of the Quebradillas limestone. As one by one the familiar Bowden and Santo Domingan Miocene species were identified by actual comparisons with specimens from Santo Domingo and Jamaica, this horizon became a certainty. Such forms as *Phos costatus* Gabb, *Phos fasciolatus* Dall, *Murex messorius* Sowerby, *Marginella coniformis* Sowerby, *Olivella muticoides* (Gabb), *Drillia consors* (Sowerby), *Haminea granosa* Sowerby, *Divaricella prevaricata* Guppy and *Malea camura* Guppy indicated very strong bonds of relationship. A very beautiful foraminifer similar to one I found in the Dominican beds was also present though rare.

As yet, however, I have not been able to satisfactorily distinguish in northern Porto Rico the two formations that we found in northern Santo Domingo and designated as the upper or *Sconsia* and the Lower or *Aphera* formation. Hence it seems best to refer the Quebradillas fauna to the Bowden which also contains mingled elements.

A striking and very common species of the Quebradillas limestone is *Metis trinitaria* from the Caroni Series of Trinidad, from Barbuda, and Santiago de Cuba. This species is not reported from Bowden, nor did we find it in our sections in Santo Domingo, but the shell in the Heneken collection from that island, called *Tellina biplicata* by Guppy, was probably this Metis.

(2) The next faunal unit differentiated was that of the *Orthaulax*. This was kindly examined by Dr. Dall who thought it a new species, nearest to *Orthaulax pugnax*. As Dr. Reeds found it near Aguadilla, I am naming it *aguadillensis* in my forthcoming detailed report. No shells were found associated with it, only a single sea urchin that has been submitted to Dr. R. T. Jackson but not yet reported on.

(3) The most peculiar fossils in the collections are very large internal molds of a turreted shell apparently an enormous Cerite. These seemed worthy of sectional rank as they differ in a number of respects from the subgenus *Campanile*, and I am suggesting for them a new section *Portoricia*.

This horizon with the great Cerite, Dr. Reeds assures me, from his field observations, lies below the *Orthaulax*,

although there is no actual superposition, as they occur in different localities, twenty-nine kilometers apart.

Dr. W. H. Dall in a letter dated June 12th, writes regarding the Cerite molds, the *Orthaulax* and a few other specimens that he was so good as to pass judgment on "Most of your material recalls the Flint River upper zone, or Tampa silex bed horizon."

(4) The fauna of the green shales on Rio Collazo near San Sebastian is a very interesting and unique one. It has at first glance what one might call a false Eocene aspect. The fossils are all greatly distorted from pressure. The most abundant and characteristic shell is a *Clementia* like *dariena* from Gatun, but smaller and less ventricose. It appears to be the Oligocene ancestor of the Miocene *C. dariena,* and I am naming it *C. rabelli.* With it was a new *Arca,* most like *A. balboai* Sheldon (=*A. dalli* Brown and Pilsbry, name preoccupied), which Dr. Vaughan lists from the Culebra formation. A representative set of Rio Collazo fossils was sent to Professor Gilbert D. Harris, of Cornell University, well-known as our leading American molluscan Eocene paleontologist, with the request that he would kindly let us know if they recalled any Eocene forms. Professor Harris replied, in a letter dated May 27th: "I cannot say that your fauna is related closely to any Eocene fauna with which I am acquainted and my impression is that it should go along with the later Tertiary."

(5) On the south side of the Island near Ponce, Dr. Reeds collected a large number of oysters all of one species, and quite unlike the oyster which is very common in the Collazo shales, and also entirely different from the Guanica species. The Ponce oyster I identified as probably *Ostrea cahobasensis* Pilsbry and Brown, the type of which was found near Las Cahobas and south of Thomonde, Haiti. Dr. Reeds sent a shell to Dr. Pilsbry who very kindly compared it with his type and writes, "I am disposed to identify it provisionally with the Haitian species."

Mr. W. F. Jones[11] places the Las Cahobas and Thomonde beds somewhat below the Anguilla horizon. I have placed these beds slightly higher in the following correlation table, because of the fauna which Mr. Jones lists from them[12] and because he does not mention finding *Orthaulax* in the Haitian beds.

[11] Jour. Geol., 26, p. 744, 1918.
[12] *Op. cit.,* p. 738.

The Ponce beds with the *Ostrea cahobasensis* would naturally tie up with these Haitian beds, but what the exact time relation of the Ponce bed is with those on the northern side of Porto Rico, I do not know.

TENTATIVE CORRELATION OF THE PORTO RICAN TERTIARY FORMATIONS

| | | Subdivisions of the Arecibo Formation | Porto Rico North Side | Porto Rico South Side | Santo Domingo | Haiti | Jamaica | Anguilla | Antigua | Panama | Florida | Georgia | Cuba |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIOCENE | Middle | | ? | | Upper or *Sconsia* Formation | Maissade beds | ---?--- | | | Gatun beds with *Sconsia* | | | La Cruz marl |
| | Lower | | Quebradillas limestone with Bowden fauna and *Metis trinitaria* | | Lower or *Aphera* Formation | | Bowden marl | | | ? Lower Gatun. horizon | Oak Grove sands Chipola marls | | Santiago de Cuba bed with *Metis trinitaria* and Marl at Baracoa |
| OLIGOCENE | Upper | | Aguadilla limestone with *Orthaulax aguadillensis*<br>Lares limestone with *Campanile (Portoricia) larica* | Ponce chalky beds with *Ostrea cahobasensis* | *Orthaulax inornatus* zone | Las Cahobes beds (Jones) Thomonde beds (Jones) | | Anguilla formation | | Emperador limestone Upper part of Culebra formation | Tampa formation with *Orthaulax inornatus* and *O. pugnax* | Flint River upper zone with *Orthaulax inornatus* and *O. pugnax* Flint River lower zone | Various localities of Cuba |
| | Middle | San Sebastian Lares, or Collazo shales | Rio Collazo shales with *Clementia rabelli* | Guanica shaly limestone with *Ostrea antiguensis* | ? Monte Cristi range limestone | | | | Antigua formation with *Orthaulax pugnax* | Lower part of Culebra formation | | | Coral reef at Guantanamo (Vaughan) |

(6) Dr. Pilsbry has compared our Guanica oyster with the type of *Ostrea antiguensis* Brown from Antigua. Dr. A. P. Brown's type is very badly preserved, but after making a careful comparison, Dr. Pilsbry writes: "I have no doubt of the identity."

In this Guanica horizon there are quantities of a very large foraminifer which resembles that figured by Dr. Brown from Antigua.

The Guanica beds would seem to be almost certainly approximately synchronous with the Antigua beds.

(7) The Juana Diaz shales furnished very few molluscan shells. The best were two species of *Cuspidaria* one apparently identical with *Cuspidaria islahispaniolæ* Maury from Bluff 3, Cercado de Mao, Santo Domingo. The other was new. There was also a very small *Leda*. The evidence at hand is too scanty for any definite stratigraphic conclusion regarding these beds.

### Correlation.

The stratigraphic relations, as they appear from our present knowledge of the faunal groups studied, are expressed in the accompanying Correlation Table.

**American Museum of Natural History,**
**New York City, 10 July, 1919.**

ART. XVIII.—*Geological Notes on the Pribilof Islands, Alaska, with an Account of the Fossil Diatoms;* by G. DALLAS HANNA.

The Pribilof Group of Islands, which consists of St. Paul, St. George, Otter, Walrus and Sea Lion Rock, lies in Bering Sea approximately 200 miles from other land in three directions. The islands were discovered in 1786 and are primarily known as the breeding grounds of the Alaska fur-seal herd. They have been more or less regularly visited by naturalists since the time of Ilia Wossnessensky, 1840-48; consequently they have come to be better known biologically than any other area of similar size in Alaska. Many titles to publications pertaining to the group belong to botany and zoology but by far the greater number concern diplomatic matters arising from international controversies over fur seals. Geology and paleontology have received a share of attention.

*Location.*

The islands are situated on the "Bering Sea Plateau," that level tract of submarine land forming the bottom at about 40 fathoms over the northeastern part of this body of water. They are near the southern boundary of the limits of the winter ice-sheet which conforms approximately with the boundary of the plateau.

The existing fauna and flora on the islands are derived from Asiatic and American sources so divided as to preclude the theory that they have been united to either continent since the lava outflows from which they are largely built. St. Matthew Island, Cape Newenham and the Aleutian Islands lie north, east and south respectively, about the same distance.

*General Geological Features.*

The bulk of the elevated masses is composed of lava and scoria arranged approximately in horizontal layers or forming cones. At the water line the outcroppings are in many places—and especially on the seal rookeries—basalt which has been blackened on the surface by the action of the sea-water. Above the sea or inside this basalt the color of the rocks is usually gray, olive or red

with included crystals of yellow feldspathic minerals. At one point on St. George Island the lava is built up to an elevation of 1012 feet. Some large cones, however, as Polovina on St. Paul, are composed almost exclusively of red and black scorias.

The evidence is conclusive therefore that violent volcanic action has built the islands as they exist to-day and that all traces of these disturbances disappeared before the advent of man. Casual inspection would lead one to believe they were built from the ocean floor but there are several points where a true conception of the geological formation can be had. One of the best of these is at Tolstoi Point, St. George Island. Here massive jasper[1] with grains and seams of quartz extends about 100 feet above the sea. It it without stratification. The same rock occurs above sea-level at Garden Cove, St. George Island, and that it comes near the surface at several other places on the islands is shown by the numerous pebbles and bowlders of this material on the beaches.

This massive jasper formed land masses at the Pribilof Islands before the volcanic action which built the forms which now exist. This is shown conclusively at Tolstoi Point, St. George Island, by the layer of sand rock which lies immediately above. This contains large quantities of water-worn bowlders and pebbles, water-worn shells, etc. It varies in thickness from two to ten feet and is also found at Sea Lion Rookery, Garden Cove (St. George Island), Ardiguen Rookery, Tolstoi Point, and Zapadni Point (St. Paul Island). At some of these places the sand rock does not extend high enough to expose the underlying strata but near the top of each exposure there are similar beach formations.

Immediately on top of the sand rocks there are thick beds of lava. The entire surface of all the elevated group as it stands to-day is covered with this (and scoria), so that any animals or plants which may have existed on the previous land masses must have been wiped out. The highest point which this former beach line (covered with lava) reaches above the sea at the present time is about 100 feet so that it may be safely inferred this represents the total amount of elevation of the ocean floor during the volcanic period.

[1] The identifications of the minerals as given herein were made in the Division of Geology, U. S. National Museum, under the direction of Dr. George P. Merrill.

### *Black Bluffs Exposure.*

For many years this was believed to be the only locality on the Pribilofs where fossiliferous rocks occurred. The first collections from it were made by a Russian naturalist, Wossnessensky, in 1847-48. It appeared to Dall[2] who summarized the information on the deposit up to 1896, that the early explorations yielded Miocene fossils in a lime stratum. This had completely disappeared, however, at the time of the Elliott investigations, 1872-74. In the light of recent collections it seems somewhat doubtful if Miocene fossils were ever found here and that possibly some error in locality may have been made.

Fortunately a good collection of shells has been made from this exposure because the sea is fast tearing it away. All the later gatherings were from nodules which were water-worn and occurred in the layers of scoria at the base of the cliffs. At the present time (1918) these are exceedingly scarce. The sea has eroded the hill inward beyond its crest and as the layers slope downward and backward those at the base which contained the fossils are beneath the sea. Since these nodules were detached from the parent beds and thrown up by volcanic action they do not represent the age of the layers in which they were found, and it might be possible for fossils of more than one age to have thus become mixed. Despite its imperfections this exposure is very important because of the study which it has received. A list of the mollusks found has been published. (See bibliography.)

### *Other Sedimentary Rocks.*

Besides the exposure just mentioned there are several others on the islands where sandstones *in situ* outcrop. These are as a rule near the surface of the sea and, as stated above, are underlaid by massive green jasper. In some places this was not sufficiently elevated to appear above the water but the bowlders and pebbles which may be seen on the beaches are indications here of the rocks beneath the sand rocks.

*Ardiguen Rookery, St. Paul Island.*—The sand rock at this point extends from the water to a height of 15 or 20 feet. Above it there are lavas of about the same thickness. All form a perpendicular cliff with loose rocks piled at the bottom. The elevation has been caused by

[2] **Seventeenth Annual Report U. S. Geological Survey, 1896.**

a fault which extends across the peninsula, and under one low cliff back of Gorbatch Rookery the strata are barely perceptible. There is an excellent deposit of fossils at Ardiguen but a collection has not been made.

*Village, St. Paul Island.*—The digging of a well in the St. Paul village in the spring of 1918 disclosed the fact that sedimentary rocks outcrop 60 feet above the sea near the north end. Here also they are sand rocks and lie beneath several feet of lava, the blocks of which had obscured the lower layers. At about 10 feet above sea-level there is a layer of gray marl which was bored into 30 feet without penetrating. The sand rocks contain a few mollusks and the marl contains some diatoms, neither of which have been studied.

*Tolstoi Point, St. Paul Island.*—The total height of the cliff here is about 200 feet. The sand rock again outcrops and at one fault reaches an elevation of about 100 feet. It extends for about half a mile along the base of the cliffs, offering an admirable opportunity for the collection of the fossils which are found in great abundance.

The upper layer of this sand rock is coarse-grained, very hard in most places, and contains volcanic cinders, water-worn pebbles and beachworn shells. At the highest point there was apparently a beach sand mound at the time of the lava outflow because the sand has blown away beneath and left an overhang which shows in striking manner the waves of lava as they ran down.

Three other indistinct layers can be traced beneath the hard upper layer. All are fossiliferous and decrease in hardness and coarseness toward the water. The lower layer has the consistency of marl and has springs of fresh water at one point which flow throughout the winter. It is composed largely of diatoms with some clay and fine sand. All of the layers were found to contain diatoms but they were most abundant in the lower. It is the material found in this deposit which forms the basis of this report.

A collection of mollusks was made by the writer from 1914 to 1918 and these have been studied and reported upon by Dr. William H. Dall.[3] They showed the age of the deposit to be about the same as the one at Black Bluffs

[3] Jour. Wash. Acad. Sci., vol. 9, No. 1, pp. 1-3, Jan., 1919.
*Dall, William Healey.* 1896. Report on Coal and Lignite of Alaska, 17th Annual Report of the U. S. Geological Survey.

and more recent than the St. George deposit mentioned below.

In addition to mollusks and diatoms, a bryozoan was found in this deposit; also the remains of several vertebrates which were too incomplete for positive identification. Among these were the tusk and a vertebra of a walrus; a vertebra and a carpal bone of probably a hair seal; some vertebra of a fish; and some ribs.

*Zapadni Point, St. Paul Island.*—The outcrop here is a bed of gravel about 25 feet thick lying beneath about 75 feet of lava. All form a perpendicular cliff. The gravel is loose and at one point forms a slide. No fossils have been found.

This is the last of the known deposits on St. Paul Island but the water line has not been examined from Southwest Point to Northwest Point. That the sand rock comes close to the surface near the head of the Salt Lagoon on both sides is indicated by the springs of fresh water which remain open through the winters.

*Tolstoi Point, St. George Island.*—The sand rock here is on top of about 100 feet or more of massive jasper and in some places is composed almost entirely of fossil mollusks. As stated before there has been a beach here at one time. The cliffs are almost 300 feet high and provide nesting sites for many thousands of water birds in the summer time. The sand rock is coarse-grained and varies in hardness in different places. It contains, besides mollusks, pebbles and bowlders, and several fragmentary bones (probably fish) were found. No diatoms however have thus far been seen from it. Numerous large springs flow down the cliffs from the ledge.

The collection of mollusks made here has been examined by Dall with those from St. Paul Island and he states that they indicate the St. George strata are the older. They seem to be Pliocene.

*Sea Lion Rookery, St. George Island.*—The old beach line again outcrops here and is found on top of the jasper about 50 feet above the sea. It is composed largely of rounded bowlders of large size, and there are several springs of excellent water flowing from it.

*Garden Cove, St. George Island.*—Here the formation is similar to that of Tolstoi Point just considered, except that no fossils but diatoms have been found in the sand rock. (Careful search, however, has not been made.) A

crack in the stratum permits the egress of one very large spring and in the stream flowing from it fresh water diatoms in pure gatherings can be had in great abundance. The sand rock outcrops on toward Cascade Point an unknown distance. As far as it has been traced it has large numbers of springs flowing from it and it is underlaid by massive igneous rock. On top there is the characteristic lava in horizontal layers.

The diatoms found in one small pocket were not well preserved nor abundant but the species were all represented in the gatherings from Tolstoi Point, St. Paul Island.

Although these are the only known sedimentary deposits on St. George Island it must be said that the water line around Cascade Point and around the Big Cliffs from Staraya Artel Rookery past Dalnoi Point and to Zapadni Rookery has not been examined.

### *Otter Island.*

The west end of this island has been elevated so that about 75 feet or more of sandstone has been exposed. It has not been carefully examined. On the opposite end of the island may be seen an excellent crater which has been cut into by the sea on one side.

### *Age of the Islands.*

That the fossil-bearing sandstones were elevated at the same time that the violent volcanic disturbances which covered the islands with molten rock occurred seems certain from the fact that volcanic cinders are found in more or less abundance in the topmost portions of the sedimentary layers. If the age of the sand rock can, therefore, be accurately fixed this will determine the age of the islands as they exist to-day to a fair degree of certainty and this fact would be of value in the study of such animals as the fur seal. From the study of the mollusks mentioned it seems to be post-Pliocene on St. Paul Island and Pliocene on St. George Island. A study of the diatoms indicates that the age of the two islands is the same and that it is more apt to be Pliocene than a later period.

If the age of the Tolstoi Point (St. Paul Island) beds is post-Pliocene it would be expected that the characteristic

species of diatoms as well as mollusks found therein would be found in the waters round about at the present time. But this is not the case. The common fossil species are exceedingly rare or entirely absent from the region to-day. Likewise the dominating species to-day, *Coscinodiscus asteromphalus* has not been found as a fossil. In fact several genera which would be expected such as *Campylodiscus, Arachnoidiscus* and *Aulicodiscus* were not found.

The violent volcanic disturbance which was required to pile up the mountains of lava has required a considerable period of time (years), for all traces to disappear. But only two slight earthquakes, or signs of volcanic action, have been recorded since 1786 when the group was discovered. This together with the fact that a mountain of hard lava more than 1,000 feet high has been more than half eaten away by the sea indicates that the islands in point of years are very old.

Still there is no evidence that an ice sheet of greater weight than those visiting the shores to-day has ever visited the islands. This makes it seem doubtful if they had cooled at the time of the glacial descent. Few plants and animals have become sufficiently differentiated to receive separate specific names from those of neighboring land; geologically therefore the group must be very young.

The original size of the Pribilof Islands and the rate of erosion form a subject of interesting speculation. That they were originally very much larger than now cannot be doubted because many mountains and hills facing the sea have been more than half eaten away and slope backward. One important fossil-bearing deposit has disappeared within historical times. Unless volcanic disturbances come to the rescue they must all eventually be torn down, become reefs for the restless surf to break over, and, at last, cease to exist.

It should be stated here that the reports of the finding of bones of fossil elephants on the Pribilof Islands are probably attributable to practical jokes which have been played on credulous naturalists in the past. No such bones have thus far been found that were not planted by man, according to reports of eye-witnesses to some of the pranks.

## *Bibliography of Pribilof Islands Geology and Paleontology.*

——— 1899. The Mollusk Fauna of the Pribilof Islands, in the Fur Seals and Fur Seal Islands of the North Pacific Ocean, Part 3, pp. 539-546. (Notes are given on the occurrence of fossil mollusks in the Black Bluffs formation of St. Paul Island, with a list of the species.)

——— 1919. Journal of the Washington Academy of Sciences, vol. 9, No. 1, pp. 1-3, Jan. 4, 1919. A list of the mollusks from the deposits at Tolstoi Point, St. Paul Island, and Tolstoi Point, St. George Island. Seven new species are mentioned without name.

*Dawson, George M.* 1895. Bulletin of the Geological Society of America, vol. 5, pp. 130-132.

*Elliott, Henry Wood.* 1875. A Report on the Condition of Affairs in the Territory of Alaska, U. S. Treasury Department, p. 70. (Published also as part of House Miscellaneous Document No. 83; 44th Congress, 1st Session.)

——— 1886. Our Arctic Province, p. 227. (Chas. Scribner's Sons.)

——— 1898. Seal Islands of Alaska. (Government Printing Office.) In "Seal and Salmon Fisheries and General Resources of Alaska, vol. 3. (Geological matter largely quoted from earlier publication by same author.)

*Grewingk, Constantine.* 1850. Beitrag zur Kenntniss der orgraphischen, etc., der Nordwestekiiste Amerika, St. Petersburg. (In Verhandlungen der Russisch Kaiserlichen Mineralogischen Gesellshaft zu St. Petersburg.) Pribilof Geology, p. 190. This contains the observations of Ilia Wossnessensky, 1847-48.

*Gilmore, Charles.* 1907. Smithsonian Miscellaneous Collections No. 1807, vol. 51.

*Maddren, A. C.* 1905. Smithsonian Miscellaneous Collections No. 1584, vol. 49, pp. 20-21. (Mention made of the finding of fossil mammoth remains.)

*Stanley-Brown, J.* 1892. Bulletin of the Geological Society of America, vol. 3, p. 496.

### *List of Diatoms from Tolstoi Point, St. Paul Island.*[a]

[a] The identifications of the species were either made or checked by Dr. Albert Mann of the U. S. Department of Agriculture who is an authority on these organisms.

1. *Amphora ovalis.*—Several specimens showing considerable variation found.
2. *Cymbella gastroides* Kutzung.—One valve only.
3. *Navicula* (*Stauroneis*) *phoenicenteron.*—One valve only, which differs slightly from living examples of the region.
4. *Navicula peregrina* Ehrenberg.—Two valves only.
5. *Navicula rhynchocephala* Kutzung.—One specimen.
6. *Navicula,* new species.—One broken valve of an undescribed *Navicula* was mounted.
7. *Chetoceros cinctum* Gran.—Several specimens found.
8. *Thalassiothrix nitzschoides* Grunow.—Exceedingly abundant and variable in size and shape.
9. *Melosira sulcata* Ehrenberg.—Several varieties of this excessively variable species were found in the deposits.
10. *Raphoneis amphiceros* Ehrenberg, variety.—The beading of specimens found is exceedingly coarse; center rows have only 4 beads.
11. *Actinoptychus splendens* Ralfs.—One specimen.
12. *Actinoptychus undulatus* Ehrenberg.—Two specimens.
13. *Actinoptychus,* new species.—An undescribed form of this genus was found to be abundant and somewhat variable. It is especially characterized by the large size of the beads.

14. *Stepanopyxis appendiculata* Ehrenberg.—Two specimens.
15. *Stepanopyxis grunowii* var. *inervis.*—Very abundant and spines absent on the valves.
16. *Coscinodiscus pustulatus* Mann.—The abundance of this diatom characterizes the deposit. It is excessively variable, only the more perfect examples approaching the original figure. Valves are dissimilar in shape, one being a section of a sphere while the other is a rounded cone. The species has heretofore been found but once, and then in deep water in Bering Sea.
17. *Coscinodiscus decrescens* Grunow.—Two specimens only.
18. *Coscinodiscus undulosus* Mann.—One specimen of this remarkable diatom was found.
19. *Coscinodiscus tuberculatus* Greville.—A very abundant and variable diatom.
20. *Coscinodiscus subtilus* Ehrenberg.—Two coarse examples.
21. *Coscinodiscus radiatus* Ehrenberg.—Very common and variable in size.
22. *Coscinodiscus marginatus* Ehrenberg.—Abundant and variable in size.
23. *Coscinodiscus fimbriatus-limbatus* Ehrenberg.—One specimen.
24. *Coscinodiscus excentricus* Ehrenberg.—One specimen.
25. *Coscinodiscus,* new species.—Four specimens of an undescribed species probably belonging to this genus were found. The markings are so remarkable that Dr. Mann could not say with certainty that it was not a *Melosira.*

# Art. XIX.—*The Framework of the Earth;* by W. M. Davis.

For ten or twenty years past, the discussion of various large, super-national questions has held an important place in the proceedings of geological meetings and congresses, national and international; but international action of large dimensions has not yet been undertaken with respect to the greatest of all geological problems, the framework of the earth as a whole. Such action should no longer be delayed. Astronomy has very naturally anticipated other sciences in internationalizing its studies, because its realm is extra-terrestrial and belongs alike to observers in all nations. Geologists may now to advantage follow the lead of the astronomers and, without hampering individual initiative or interfering with national surveys, attack the problem of the earth's framework in an international spirit, for all countries are parts of the same planet.

The present essay closes with a somewhat definite proposition towards that end, which may be at once outlined in this paragraph. The framework of the earth, as determined by all available recorded observations, has been studied in the broadest manner possible by the late Eduard Suess of Vienna; the conclusions reached are summarized in masterful fashion in his great work, "Das Antlitz der Erde." An English translation, "The Face of the Earth," has been prepared by Miss Sollas of Oxford and published several years ago; Emmanuel de Margerie of Paris has lately completed a French translation, "La Face de la Terre." Thus the results of the great Austrian's life work are now available in three languages. Some of his generalizations are well established; others are not so well assured for lack of data. The less assured generalizations can be best tested by directing attention to certain significant areas in which observations are wanting. Indications of these significant areas and of the particular problems that they contain would be welcomed by the geologists of the world as a guide to their future work; particularly if the indications were made by the one man most competent for such a task of all men now living; and that man is without question the scholarly translator of the French edi-

tion of Suess's work. It is with the object of calling attention to the completion of de Margerie's translation and to the importance of securing from him the necessary indications regarding the most desirable lines for super-national geological investigation of the earth's framework that this essay is prepared.

The time is fitting for international and super-national work of this kind. Never has the earth as a whole been so closely scrutinized in many relations by its many inhabitants. Never has the need of world-wide investigation been realized so fully. Never has there been a broader recognition of the value of international coöperation in the solution of great scientific problems. The actual gathering of large international congresses for scientific objects may be delayed for a time by reason of the turmoil that follows the Great War; and, as is well known, certain nations that have heretofore taken an active part in science will not be invited to attend international congresses for the present; but national and international committees are already at work on various broad questions, and the outlining of truly terrestrial investigations for discussion at the next international geological congress, whatever nations may be invited to take part in it, should not be longer deferred. In view of the leading position that de Margerie may, it is to be hoped, be persuaded to take in relation to the future super-national investigation of the earth's framework, special attention will here be given to the position that he now holds in this great subject. But a retrospect over Suess's work must first be taken.

The well-defined object of Suess's studies was to determine the general structure of the earth's crust and to infer therefrom the character of the larger movements by which the crust has been deformed. The method that he pursued in this great endeavor led him first to examine all pertinent geological records, wherever published; then to group the relatively local areas therein treated with respect to the larger structural units, usually of super-national dimensions, to which the areas belong; and finally to discuss the manner in which adjacent structural units are related to one another. Thus the work as a whole truly constitutes a treatise on the framework of the earth, and as such it well deserves to be ranked as the greatest geological treatise ever written. It dif-

fers fundamentally from the most advanced and most voluminous text-books of geology; they proceed systematically through accounts of the constitutents which make up the crust, of the processes by which the crust is modified, of the formations which the processes have produced in historical sequence, and of the organic records therein preserved. The author of "Das Antlitz der Erde" began where even the greatest of the text books end; and with the expertness attainable only by the long-continued application of a powerful intellect to a great subject, compressed into his treatise a masterful account of the external anatomy of our planet. His volumes are at once so profound and so comprehensive that their pages can be fully appreciated only by geological experts of wide training. Among these the present writer does not venture to range himself; for while the conclusions which Suess reached are of much interest and importance to geographers as well as to geologists, a geographer cannot, even if he has the needed preparation, take the time required for the thorough reading and digestion of all the analytical and synthetic pages in which Suess's conclusions are set forth; although like more devoted students of the great work, he must admire the profusion of learning and the breadth of treatment that the many pages represent.

Every reader of these volumes must be impressed with the vast accumulation of good material upon which they are based; an accumulation that is certainly creditable to geological science. Naturally enough, it is not complete. Observations in certain regions are still insufficient to serve as the basis for safe generalization; for example, large parts of the Andes are frankly left over for future discussion in the absence of competent records now available. No one can realize these deficiencies so fully as the masterful author must have done while pursuing his researches. Nevertheless the great number of well-certified records already published regarding the larger part of the continents suffices to reveal the main structural elements of the earth's framework; and this is truly gratifying for a science that is but little over a century old. Hutton's "Theory of the Earth," Playfair's "Illustrations of the Huttonian Theory," and William Smith's "Strata Identified by Organized Fossils" are famous British examples of the beginnings of

geology at the end of the eighteenth and the opening of the nineteenth centuries; but these and other early works were necessarily based upon imperfect knowledge of restricted fields, the observational study of which had not been standardized. Some of their generalizations were inevitably incorrect; yet the old masters were wise in many of their speculations, and their writings are still profitable reading, if only to learn how great a present-day science has been built up from the foundations that they and their contemporaries laid down a century ago.

Lyell provided in his "Principles of Geology" a broader establishment, through the middle of the nineteenth century, for many of the generalizations that his predecessors had formed. His great contribution to earth science was the fuller demonstration that gratuitous overdrafts made out by geological speculators on the Bank of Terrestrial Forces must be returned, marked "No Funds." Yet that able and fair-minded uniformitarian nowhere gave adequate treatment to the great problem of mountain-making; and he was so little constrained by the historical geology of the continents, as known in his time, that he felt free to suggest a fundamental rearrangement of land and water at so late a date as the Pleistocene, in order to account for the climatic changes which the Glacial period demands. Even when the latest of his own revisions of the "Principles" appeared, geological exploration was so little advanced that no general summary of earth structure was legitimately possible.

Still less possible was it some fifteen years earlier, when Elie de Beaumont announced his venturesome scheme regarding a geometrical arrangement, a "pentagonal network," of violently upheaved mountain ranges. It is interesting to recall that this scheme was set forth in an essay originally intended to give a summary of the science of geology in d'Orbigny's "Dictionnaire universelle d'histoire naturelle"; but as the dictionary was too far advanced for the essay to appear under G, it was named "Montagnes," and thus postponed to M, so that the busy author might have more time for its preparation. When M was approached, the essay, still belated, was renamed "Soulèvements et Révolutions du Globe"; and when "Soulèvements" was reached the essay was again deferred to "Systemes de Montagnes." In the meantime the manuscript had far

outgrown the space allotted to it; hence only part of it appeared in the dictionary: the completed statement, still set up in the narrow form of dictionary columns, came out in three small but thick volumes in 1852. The system thus set forth now seems to have been more illuminated by lamplight than by daylight. In the very country where the pentagonal network longest held ground under the authoritative teaching of its inventor, it has now been completely replaced by the non-geometrical and highly irregular mechanistic system, as it may be called, which the great Austrian geologist has developed, and which many French geologists have in recent years done much to support.

It is not the intention of this article to attempt a review of Suess's conclusions; their general nature may be apprehended from a chapter in the final part of the work entitled "Analyses," in which the chief results gained in the previous volumes are summed up, especially with regard to the leading structural elements of the earth, among which, although they are of different nature and area, instructive comparisons may be instituted. The chief and best known of these are: Laurentia in northern America, a vast area of ancient rocks on which Cambrian strata still lie horizontal and on which no Mesozoic strata were deposited until the time of the great Cretaceous transgression. (2) The Caledonids, a belt of pre-Devonian folding, which stretches from northern Ireland across Scotland and western Scandinavia to Spitzbergen. (3) The vast Eurasian edifice, the greatest of all the elements, with its medial area of "Angara" in northern Asia, like Laurentia in consisting of ancient rocks on which horizontal Cambrian strata lie unconformably; this medial area being bordered on the south by great mountain chains of medieval or modern origin which frequently show a loop-like arrangement, and which continue so far as to envelop the northern hemisphere; for one wing of the mountain chains stretches far eastward around the border of the north Pacific into the Rocky Mountains of northwest America, and another stretches far westward, possibly as a once continuous land mass, across the Atlantic into the Appalachian system; thus our Laurentia is enclosed on the southwest and southeast by extensions of the Angaran mountain border. (4) The Gondwana continent, originally extend-

ing as a continuous land mass from middle South America across the then undeveloped Atlantic basin, then widening so as to include all Africa except the folded ranges of its northwestern and far southern borders, and finally crossing the area of the Indian Ocean to the peninsula of India: all this huge element being, like Laurentia and Angara, long undisturbed and having no Mesozoic cover earlier than the Cretaceous overlap. And so on with five other elements of greater or less size and of more or less definite establishment. Let it be noted in passing that it is because of the transverse or discordant attitude of the present Atlantic basin with respect to the remains of the great crustal elements that formerly crossed it, that its border contrasts so strongly with the tangential or sympathetic attitude assumed by the border of the Pacific basin with respect to its limiting elements: this contrast being one of the most striking characteristics of the earth's larger features.

Next let it be noted that it is especially with regard to the structure and origin of mountain chains that the broad generalizations established by Suess have carried geology so far forward from Lyell's mountainless uniformitarianism, and so far from de Beaumont's fanciful network of violent upheavals: and also very far beyond various other speculations regarding the origin of mountain chains, in which upheavals and compressions were combined in various proportions. For Suess showed that all the greater mountain ranges contradict all theories of axial upheaval and two-sided symmetry, and manifest instead a unilateral structure between a backland or interior area, outward from which the unsymmetrical folding and overthrusting of mountain-making deformation has proceeded, and a relatively rigid foreland or exterior area, towards which the overthrust crust advanced, often with a convex frontal border; while a deeply depressed trough, more or less filled with sediments, is usually found in front of or included within the mountain belt of advancing deformation. But although the general structure of mountain ranges thus appears to be correctly worked out, it is highly significant that neither the unit areas of ancient rocks—Laurentia, Angara, Gondwana—nor the mountain ranges that border them can be reduced to any geometrical system. Both the undisturbed areas and the deformed

belts vary in dimensions, in pattern, and in arrangement. If the framework of the earth's crust is modeled on a geometrical plan, the departures from the plan are more conspicuous than the plan itself. Thus while clearly setting forth the dominant structural features of the actual earth, Suess exhibited a fine scientific prudence in not following the Procrustean habit of some of his predecessors, who have attempted to force the framework of the earth to fit a systematic and more or less preconceived scheme. The chapter in which the "Analyses" are summarized must indeed be disappointing to those who expected to find in it the specifications of a patent earth. This restraint from over-generalization is wise: it goes well with the marvellous marshalling of geological records from all parts of the world, in view of which we repeat that Suess's volumes constitute the greatest geological work ever published.

One of the most remarkable features of the work is that its fundamental thesis regarding the asymmetrical structure of mountain chains, which is now supported by so vast a body of evidence, was well developed in the author's epoch-making essay on "Die Entstehung der Alpen," published in 1875, before "Das Antlitz der Erde" was begun. Various phrases from that essay might be repeated with little modification in the chapter on "Analyses," which forms a closing part of the later three-volume work. Indeed, it is perhaps because of the great success of his main thesis that the author has been led to hold with too great tenacity to certain other early-formed opinions, which find less confirmation in later and wider study. Masterful as the work is, repeated examination of its successive volumes as they appeared has aroused the question whether the adopted method of treatment was sufficiently mobile for so rapidly expanding a science as geology. The enormous erudition of the author and his unending capacity for analysis and synthesis are most admirable; but his mind seems to have been ponderous rather than nimble. Alternative solutions are not always treated with equal hospitality. The method of multiple working hypotheses is not conspicuously employed in the solution of disputable problems.

It is concluded, for example, that Laurentia and other ancient areas have been long undisturbed because they

became at an early date more rigid than the rest of the crust, and therefore the adjacent weaker belts suffered crushing and deformation: but this tacitly implies a comparatively uniform application of crushing forces; for if the forces were unequally applied, belts of yielding might be developed in broad areas of uniform resistance. Again the whole discussion of mountain chains has been conducted under the postulate that dislocations and deformations of the crust result from a diminution of earth volume, and that they are all either radial or tangential; yet while tangential movements are recognized as including folding and overthrusting, radial movements are taken to include only down-settlings or subsidences, all vertical upheavals being excluded, except those that result from tangential crushing. A striking example of this narrow thesis is found early in the great work, where Powell's interpretation of the Uinta mountains as an anticlinal upheaval, between less upheaved areas on either side, is reversed into an interpretation of adjoining lateral areas as having been lowered by wide-spread subsidence, while the intermediate anticlinal mass of the Uintas remained relatively fixed.

Nothing better illustrates the ponderosity of Suess's mind than the tenacity with which he held to this thesis in spite of the enormous magnitude of the subsidences that it involves. When the doctrine of no upheavals is applied to an isolated mountain mass like the Harz, the highlands of which exhibit forms of moderate relief eroded upon deformed structures, it has to be supposed that, if the Harz stood still, subsidence must have lowered not only the surrounding land area but also all the oceans of the world and all the continents that did not then emerge from the lowering oceans. This calls for an enormous contraction of the earth. The isolation of every other highland, large or small, that has been accomplished by the subsidence of the surrounding regions at a date different from the dates of other isolating subsidences, similarly involves a great, world-wide contraction. Surely the total diminution of earth volume thus called for is so great that the more economical doctrine of local upheavals should at least be given careful consideration before it is rejected. Yet no sufficient consideration of this open alternative is presented in Suess's works. Instead, the doctrine of subsidence, as if repre-

senting an essential truth, is vividly illustrated by the case of a post standing just beneath the ice of a frozen pond, so that as the water is drawn off the ice above the post remains at a higher level than that of the subsiding ice around it. This illustration is so striking that the unwary reader might fairly regard the doctrine it represents as having been decisively demonstrated; yet a careful search fails to disclose any valid proof of it whatever. The reason for its adoption was simply that Suess, as he frankly states, could not conceive of any telluric mechanism by which an upheaved mass could be long sustained in its upheaved position: hence he settled down upon the doctrine of no upheavals, instead of leaving the question unsettled, as it should have been left in the absence of deciding evidence.

One of the most illegitimate applications of this very questionable doctrine is found in a chapter on the Pacific, in which the occurrence of high-standing atolls is considered. It is there concluded from the scanty records available thirty years ago that all such atolls have essentially the same altitude, and hence that their emergence must be due to the subsidence of the ocean; and confirmation of this is thought to be found in the occurrence of certain terraces of about the same altitude on the Atlantic border of the continents. Yet as a matter of fact, not only are the high-standing atolls very unlike in altitude, but they are also very unlike in the amount of dissection that they have suffered since emergence; hence it must be inferred that their emergence took place at different dates as well as by different measures; and emergences thus characterized are evidently not so well explained by repeated subsidences of the ocean—and of all the islands and continents that did not then emerge—as by local upheavals of ocean-bottom areas in the region of the emerging atolls at different times and by different amounts. As to the terraces on the Atlantic borders of the continents, the records concerning them are by no means sufficient to prove that they have all been emerged by the same amount and for the same length of time; yet without such evidence they are incompetent witnesses to the doctrine of no upheavals.

In still another respect the whole treatment of mountains is inadequate, as has often been pointed out by Suess's reviewers; namely, in the omission of the

changes that mountains have suffered by erosion during and after their first deformation. If this phase of mountain study found its application only in the explanation of their present form, its omission from a treatise on earth-crust structures would be proper enough, even though the treatise be entitled "The Face of the Earth"; but the study of mountain forms, as the joint result of deformation and erosion, has come in the last half-century to be an important means of interpreting the disturbances that the mountains have suffered. It has indeed been thus learned that many mountains owe the altitude they to-day possess not to the tangential deforming forces by which their strata were first crushed, but to forces of later date and simpler action by which, after the first-deformed mass had been eroded to moderate relief at a moderate altitude, it was upheaved with more or less warping and fracturing and with no indication of tangential compression, along lines that are not necessarily coincident with those of its earlier disturbance.

A single example of the manner in which erosional studies bear upon deformational studies may be taken from Suess's first volume, an example of all the more importance because it illustrates a serious danger to which the author of a work of compilation is exposed; namely, that of accepting the conclusions of a distant observer without means of testing their correctness. The case in point is that of the supposed 40,000-foot fault along the western border of the Wasatch range of Utah, as reported by King. Here Suess adopted King's measure, without perceiving that, if a far-advanced cycle of erosion be interpolated between the folding of the Wasatch rocks and the faulting of the Wasatch range, the measure of faulting may be reduced to a quarter or less of King's extravagant estimate. As to the acceptance of conclusions reported by the many observers cited, it is not to be questioned that Suess as a rule exercised excellent judgment and sagacity; but as to the omission of erosional processes from a study of the face of the earth, this would seem to be because the physiographic method of investigation employed in the interpretation of these processes was not embraced in Suess's view of geological science, and that he never acquired it. Erosional processes were omitted because he did not understand their application: and in view of their omission it

is the framework of the earth rather than its face that "Das Antlitz der Erde" treats.

In spite of these various omissions and limitations, the framework of the earth is ably treated in Suess's volumes. No one can look them over, much less read them carefully, without experiencing an enlarging expansion of his previous conception as to the content of geological science. The local items through which acquaintance with field geology begins, the areal studies through which it advances, the reports of national surveys through which it is matured, are all far transcended by the comprehensive views concerning the structure and development of earth-crust elements, as Suess has summarized them. In the measure that they are apprehended, one gains a grasp of problems never before imagined, an insight into the possibilities of geological investigation never before realized. Here indeed flows a great main stream of thought, toward which all previous studies are related as gathering rivulets and contributory branches. Here is a broad current of investigation directed to an object of extraordinary dimensions, the full attainment of which may be well regarded as the geological duty of the present century. Great honor is due to the master who opened this highway and led us so far along it. How can we best make further advance? That question will be answered most wisely after we examine the French edition of Suess's masterpiece.

Imagine the courage and patience involved in undertaking the translation of a voluminous work, the completion of which in more than 3,000 pages of large octavo print has occupied over a quarter century! Such were the qualities possessed and such is the task accomplished by de Margerie in bringing out "La Face de la Terre," the French version of "Das Antlitz der Erde." The project was conceived in 1890, and the first volume of the translation, the original of which had been published in two parts in 1883 and 1888, appeared in 1897, with a preface by Bertrand. For the second volume the German and French dates are 1888 and 1900; for the third, which like the first was issued in parts, the dates of the original are 1901 and 1909, and of the translation, 1902, 1911, 1913 and 1918. It is the completion of this great undertaking by the appearance of the last of these final parts, bearing an admirable portrait of Suess as a frontispiece and

closing with a graceful epilog by Termier, that we here celebrate.

Seventeen collaborators have translated thirty-five chapters of the imposing work, but de Margerie himself, besides supervising the whole, has translated the other twenty-three chapters or roughly two-fifths of the whole; and for good measure he has added many illustrations and a vast number of bracketed footnotes, and has prepared a supplementary volume of 258 pages containing an elaborate table of contents and index, concerning all of which more is said below. The completion of the work has naturally been delayed by the Great War; the press of Diéval, employed by the publishing house of Colin, had to be removed from one side of Paris to the other as a safeguard against a threatened advance of the Germans; and the paper of the final parts is somewhat lighter than that previously employed, as if indicating a war-time economy. To carry through a scientific task of such magnitude during the strain of a frightful invasion deserves mention along with the completion of the subterranean canal near Marseilles and the finishing of the tunnel under the Pyrenees in the same period of fateful stress.

It is by no means a simple translation that de Margerie has given us. "La Face de la Terre" is not the work of a mere bilinguist, but of a scholarly geologist, to whom the literature of his science is known by content as well as by title as to no other man now living. Yet the French version is thoroughly loyal in presenting the meaning expressed by the Austrian author in the original work, unmodified by occasional better interpretations that have come from later studies. Only very rarely is the correction of an unsound generalization introduced, and then always in recognizable form, as in the footnote which briefly states that the latest researches do not support the distinction which Suess had adopted between volcanic rocks of the Atlantic and the Pacific basins. Where technical German terms are not completely represented by the French equivalents, the German words are repeated in parentheses. Readers who prefer the simple directness of French to the complicated inversions of German may therefore rest assured that they will find in "La Face de la Terre" all the substance that is contained in "Das Antlitz der Erde."

But they will find more; for de Margerie has used his marvellous bibliographic knowledge to enrich the translation by adding a vast fund of references as well as a large number of illustrations not contained in the original work; all these additions being pointed out with scrupulous conscientiousness, the new references enclosed in brackets, and the new illustrations marked with an asterisk in the index volume, where all maps and figures are conveniently grouped geographically in a separate list. The French translation thus serves even better than the German original as an introduction to the structural geology of the world, with especial reference to such problems as are most directly related to the study of earth-crust elements. The use of the translation is moreover facilitated by an excellent index, representing an enormous amount of fatiguing work; it occupies 176 pages of the supplementary partial volume, and contains upwards of 8,000 headings with over 50,000 page references. The French version is, therefore, destined to become the working basis of the future investigations, which it is to be hoped will be the main and great outcome of Suess's studies.

As such, "La Face de la Terre" may be used to great profit by advanced students who set out, under the guidance of their professor, upon a winter's indoor campaign to acquire mental possession of a selected crustal element; not alone with the object of learning its structure as described by Suess, but also with the intention of testing the accuracy of his descriptions and generalizations by confronting them with the new material to which de Margerie's added references lead. Such a campaign must, to be successful, be conducted in the neighborhood of a good depot of munitions, where the geological literature of the world is accessible. In case the campaign cannot be undertaken because the near-by depot—or library—is deficient in material, let the librarian be urged to complete his collection by ordering as soon as possible all the works to which reference is made in the original and the added footnotes of "La Face de la Terre." Any library thus equipped will be a geological stronghold indeed.

Yet even with a well-stocked library at hand, how difficult is the studious reading of Suess's work, in whatever language it is attempted! Its pages abound in place

names, the location of which had doubtless become familiar to the erudite author by long study; they must become similarly familiar to the student-reader before he can fully acquire Suess's meaning; for of what avail are Simferopol, Hierlatz, Matchin, Dobrogea, and Theodosia, which occur on one single page, and Tummo, Tassili, Azdjer, Mouydir, Issaouan, Temassinnin, Ahnet, Gourara, Tin'ret, and Homra, which occur on another, so long as their relative positions are unknown. Evidently if the spacial relations of the formations and structures here described are to be correctly visualized all these place names must be looked up and identified on maps.

It is the same with names of fossils, such as *Ceritium concinnum, Proto rotifera, Ostrea longirostris,* and with names of rocks, such as ophrite, tonalite, tephrite, and stronalite, and with the names of formations such as Lutétien, Rhétien, Hercynian, and Westphalien; for all these words are likely, from whatever language they may be derived, to be Greek to most students, unless the reading of the text in which they are so plentifully strewn is interrupted long enough to learn their real significance; and significance they surely have, otherwise they would not be introduced. But after their significance is learned by patient plodding, the student will do well to present to his associates a general statement of the matters at issue, and to omit from this statement as many local and technical names as possible.

A winter's campaign of the kind here suggested would surely profit those who carried it through; but it is not as a text-book for even the most advanced university classes that "La Face de la Terre" best serves. The book is a compendium of earth structure for the use of mature geologists; it represents the most advanced line of professional research, from which a general forward movement by experts the world over should be made upon regions not yet occupied. The study of its learned pages will inspire the exploring geologist to new efforts. The Andes, for example, as already said, remain incompletely treated for lack of records. How impatiently must we older workers wait for the results of new researches there by our younger colleagues of whatever nation! How welcome would be a research fund, administered nationally or internationally, from which support could be given to well equipped and well-directed geological enterprise

of the kind here suggested; and how abundantly sufficient would such a fund be, if it were provided in appropriate measure by captains of mining industry who have so largely profited from the work of geological experts in the past, and who are learning to depend more and more upon such work in the future!

Yet even without such an imagined fund—the realization of which is, however, by no means only a remote and fanciful dream—the working geologists of the world will, while fortifying the positions already gained, push forward from them and transform new territory from geological barbarism to geological civilization. Just as the last half-century has seen nearly all the blank spaces on the geographical map of the world filled in with outlines of their larger topographic features, so the next half-century will see the blank spaces on the geological map of the world invaded and taken possession of by an international color scheme. But for such a movement a geological commander-in-chief of international reputation is needed to direct the operations of the new offensive; and this commander must not only be thoroughly informed as to the strength or weakness of the points already held; he must also have a broad view of the terrane over which the advance is to be made, in order to direct the attack where it can be delivered to best advantage.

It is a great good fortune for geological science that precisely such a commander is now living in the person of Emmanuel de Margerie. He is a man of wide personal acquaintance; a thorough scholar in geology and geography, extraordinarily familiar with all books and maps bearing on earth science, and possessing an intellect that represents Gallic agility rather than Teutonic ponderosity. Moreover, he possesses a minute acquaintance with all the chapters of the German and the French volumes, through having either worked them over in the translations of others or translated them himself. He can, better than anyone living, point out the districts in which new observations are needed to verify the supposed extensions of elements of crustal structure; his advice regarding fields that need special attention will, therefore, be most helpful to exploring geologists. He, more penetratingly than any other geologist, can indicate those parts of Suess's generalizations and theories which

need inspection and corroboration, and to which further work should therefore be directed. If the restraint exercised in the translation of "La Face de la Terre" were withdrawn, a critical evaluation of the whole work by its translator would be of immense assistance to the geologists of the world. And the same translator might be, more safely than anyone else, entrusted with the preparation of supplementary bulletins, to be issued at intervals of from three to five years, in which the progress of geological exploration should be summarized, not so much with respect to the countries in which they are made or to the geological formations which they describe, as with respect to the earth-crust elements to the definition of which they contribute.

Thus a revision and an extension of Suess's work might be internationally conducted. Detailed studies might be made of the exceptional features by which certain elements locally depart from the generalized structure of the elements to which they belong. Wisely directed attention might be given to the ancient deformations of the long afterwards undisturbed regions, like Laurentia and Angara and Gondwana; and coördinated effort might thus be made to extend the beginnings already outlined in the direction of interpreting the Archean framework of the earth, upon which the more modern framework that Suess deciphered has been superposed.

Where can our efforts towards the attainment of these geological ends be best begun? In my opinion, formed in as detached and impartial a manner as possible, the United States is at present the country best adapted for the beginning, because we, of all the nations geologically competent for so great a task, are also of all the larger nations least impoverished by the Great War. We are indeed likely for some years hence not to retrench our undertakings as an aid toward recuperation, but rather to extend our enterprises in evidence of our undiminished strength; we shall probably embark upon a career of world-wide activity, scientific as well as commercial, and on a greater scale than ever before. It behooves us all to see that that career shall be well wisely planned and well conducted; and it behooves the geologists among us to enlarge our vision to the utmost in order than our share in the coming enterprises shall not be neglected.

A movement is indeed now under foot to invite M. de Margerie to spend next winter with us, visiting various universities and talking with their professors and advanced students in geology on such questions concerning the framework of the earth as he regards most interesting, either because they are already well demonstrated, or because they are most in need of being better demonstrated. If he comes to this country he will undoubtedly be asked to attend the winter meeting of the Geological Society of America where he might give an address on the future exploration of the framework of the earth; and it is to be hoped that that vigorous Society may offer to publish, at such intervals as de Margerie shall deem fitting, the bulletins above mentioned in which the progress of exploration of earth-crust elements shall be summarized, provided he undertakes their preparation. It is possible that the Council of the Geological Society will plan a symposium for some future meeting, open to all members, on the great question of world structure; as a result of which all later communications might, in so far as they deal with structural problems, be habitually presented as parts of and in relation to the earth-crust elements within which they stand, just as stratified formations are now habitually presented with reference to the standard time-scale of historical geology. As a further step toward the desired end of systematic world-wide exploration, a committee of the Society might be appointed to coöperate with the Geology and Geography Division of the National Research Council and with the International Research Council of National Scientific Academies, in encouraging research along the lines that it is to be hoped de Margerie will indicate.

It is now about forty years since Suess began "Das Antlitz der Erde," and thirty years since de Margerie began its translation. The half-century anniversary of either of those dates would be a fitting occasion on which to celebrate the progress in the study of earth framework to which they lead the way; and such a celebration would be the natural opportunity at which an international study of earth framework should be reported. The opening of the year 1920 is none too early to lay plans toward such an end.

**Cambridge, Mass.**

## GEORGE FERDINAND BECKER.

On April 20th, 1919, Dr. George Ferdinand Becker died at his home in Washington at the age of seventy-two years. With his death we offer a final tribute of respect and honor to one of the last of that splendid group of pioneer geologists which was brought together by the famous Survey of the Fortieth Parallel, the founders of the U. S. Geological Survey. Clarence King, the central figure of the group, has long since gone from among us, but his three distinguished collaborators, Emmons, Hague and Becker, have but lately finished their tasks and left to other hands, hands which they themselves had carefully trained, the great problems which they so courageously mapped out.

With but a single interruption of two years (1892-1894) Dr. Becker was a "Geologist in Charge" or chief of division in the U. S. Geological Survey from its establishment in 1879 to the time of his death, a period of almost forty years. In this position, which he preferred to any other which the Survey offered, he found opportunity to initiate the many new directions of research with which his name stands inseparably associated, and he was spared much of the dull administrative routine of Washington departmental life which he particularly abhorred. Indeed it may be said of Dr. Becker that the advancement of these various lines of geophysical research was the dominating purpose of his life. Many times during the last twenty years I have heard him say, with that intensity of expression and of speech so characteristic of him when in conversation upon the subject he loved, that the study of the interior of the earth was the only thing really worth while.

Though born in New York City (January 5, 1847) Dr. Becker's early life was spent in Cambridge, Mass., where his preference for natural science rather than sports brought him early into contact with such men as Benjamin A. Gould, Jeffries Wyman, Benjamin Pierce, the elder Agassiz and other distinguished contemporaries, and gave directive impulse to his earlier studies. He was graduated from Harvard in 1868 and went abroad at once, taking advanced degrees at Heidelberg in 1869 and at Berlin (Royal School of Mines) in 1871. Neither did he neglect the practical side while abroad, for he was

accustomed to speak with some pride of having "begun life" as a "puddler" while still in Germany.

Upon the completion of his education he went to California, partly in pursuit of health, which in early life appears not to have been rugged, and partly from interest in mining and metallurgy, which was his major subject of study while abroad, and became instructor in those subjects at the State University at Berkeley. There he came in contact with Mr. Clarence King, who was then engaged upon the Survey of the Fortieth Parallel.

Mr. King's inspiring personality aided perhaps by the influence of his two younger associates, Messrs. Emmons and Hague, evidently attracted Dr. Becker strongly, for he became deeply interested in the geological problems developed during that Survey and one of them, the Comstock Lode, later became the subject of what is perhaps Dr. Becker's best-known geological memoir. (Geology of the Comstock Lode and Washoe District, published in 1882.)

In 1879 when Mr. King was invited by Congress to organize the U. S. Survey and to become its first director, Dr. Becker was among the first called to Mr. King's side, and here we encounter almost immediately the pioneer quality of Dr. Becker's mind. Notwithstanding the utilitarian demands of the times and the purposes (then utilitarian also) of the Survey, namely to discover and record the mineral resources along the line of the newly-opened trans-continental railroad (Union Pacific) and adjacent territory, we find Dr. Becker seeking out two physicists (Dr. Carl Barus and Dr. William Hallock) to be his assistants and initiating the first of the geophysical studies which thereafter became his chief interest. The details of his plan as conceived at that time are nowhere formulated, but he evidently had as an immediate purpose a study of the origin and growth of ore bodies, and I think, even at the outset, he had already in his mind a systematic physical and chemical study of the formation of igneous rocks. At all events the first publications to issue from the Laboratory soon after established in one of the towers of the Smithsonian Institution, had to do with the physical instruments, if they may be thus collectively described, necessary to such a task. I refer to the development of apparatus for the measurement of the high temperatures involved and of a trustworthy

scale in which to express and compare them, of appropriate means for determining and expressing rigidity, viscosity and other determinative qualities.

The program was evidently directed to a quantitative study of igneous rocks but did not then reach so far. Nearly ten years were consumed in the preparation of the weapons for the attack, which, from any viewpoint, whether physical or geological, was at that time a herculean task. Then the political upheaval of 1892 intervened to put an end to the undertaking through the familiar Washington method—the discontinuance of appropriations. Meanwhile and for some years thereafter Dr. Becker turned to more strictly geological subjects and published many well known monographs:

Geology of the quicksilver deposits of the Pacific slope (1888),
The crystalline schists of the Coast Ranges of California (1891),
The interior of the earth (1893),
Some queries on rock differentiation (1897),
Fractional crystallization of rocks (1897),
Report on the geology of the Philippine Islands (1901),
Present problems of geophysics (1906),
The age of the earth (1910),
Isostasy and radioactivity (1915).

But the necessity for a strict and more comprehensive application of physical law and method to all genetic problems of geology was not for a moment lost sight of and in the "Finite Homogeneous Strain Flow and Rupture of Igneous Rocks" (1893) we recognize a splendid attempt to define and formulate in precise terms some of the relations in the science of "rock mechanics." This again was a magnificent task of pioneer quality and of extraordinary difficulty, but was not immediately fruitful because clothed in somewhat abstruse mathematical form. This paper is destined to exert a considerable influence upon future geological thought (geodynamics).

In 1900 Dr. Becker was able to reëstablish his (geophysical) Laboratory with the writer as his assistant. The work was resumed substantially where Barus and Hallock had left it in 1892, but with the advantage of more appliances, and proceeded with less interference. The first paper appeared in 1904 (The Isomorphism and Thermal Properties of the Feldspars) and contains an

introduction written by Dr. Becker in which the purpose and progress of his thought in this direction is briefly but clearly set forth.

In this year also the Carnegie Institution of Washington came to the aid of the undertaking and increased both its scope (to include chemistry) and its resources. In 1907 a separate and more appropriate laboratory building was provided by the same Institution and here he carried out (in collaboration with Mr. Van Ostrand) the experimental work on schistosity, elasticity and diffusion which occupied the closing years of his life. The major portion of the results of this later activity is still unpublished.

Dr. Becker enjoyed a wide acquaintance and received many honors both at the hands of his colleagues and of foreign learned bodies. He was elected to the National Academy of Sciences; also to the Presidency of the Geological Society of America in 1914.

In thought and manner Dr. Becker was a true pioneer, absolutely fearless, impatient of limitations, quick to get at the heart of a problem, direct and vigorous in its prosecution and with untiring spirit, even under the strain of protracted illness which clouded the closing years of his life.

Arthur L. Day.

# SCIENTIFIC INTELLIGENCE.

## I. Geology.

1. *Geology and Ore Deposits of Tintic Mining District, Utah;* by Waldemar Lindgren and G. F. Loughlin. U. S. Geol. Survey, Prof. Paper **107**, pp. 282, 39 pls., 49 figs. 1919.—The Tintic has been for many years an important silver-lead district and lately has also become prominent as a copper producer. It was first studied by the Geological Survey in 1897 but because of the great amount of underground work done since that time and the discovery of many new facts about its geology it seemed advisable to make a resurvey of the area. The field work for this report was done in the years from 1911 to 1914.

The Tintic district lies in the East Tintic Mountains in Juab and Utah counties, about 60 miles south of Salt Lake City. The Range is composed of Paleozoic sedimentary and Tertiary igneous rocks. The sedimentary rocks, which include quartzite and limestone, occur in a series of folds the axes of which have a general northerly trend. The district is extensively faulted. The igneous rocks, which cover the greater part of the area, are mostly effusive but include a few stocks and dikes. They consist of rhyolite, monzonite, latite, andesite and small quantities of basalt. The eruption of these rocks took place after the sedimentary rocks had been folded, faulted and eroded into topographic forms much like those of to-day.

The ore deposits of the Tintic district have been formed by replacement and filling along fractures. The ore minerals are enargite and galena with subordinate amounts of pyrite, sphalerite and tetrahedrite. The chief gangue minerals are barite and quartz. The depositing solutions were warm waters ascending in the monzonite area while this rock was still hot. The ore deposits are to be found both in the igneous and the sedimentary rocks, the latter being the more extensive and important. The Tintic district is remarkable for its low water-level which may lie more than 2000 feet below the surface. The oxidized zone, therefore, penetrates to unusual depths. A long list of secondary minerals, some of them quite uncommon, are to be found in the district. More than 80 different mineral species have been noted in the ores.

The total value of the mineral products of the district through 1916 is estimated as $169,000,000, divided as follows: silver $78,000,000, lead $32,000,000, gold $31,000,000 and copper $25,000,000. W. E. F.

2. *The Genesis of the Ores at Tonapah, Nevada;* by E. S. Bastin and F. B. Laney; U. S. Geol. Survey, Prof. Paper **104**, pp. 50, 16 pls., 22 figs. 1918.—The study of polished specimens of the Tonapah ores by modern microscopic methods has re-

vealed some new and interesting facts concerning their genesis. The solutions that deposited the great bulk of the Tonapah ores were, it is believed, exudations from cooling buried bodies of igneous rocks. The earliest minerals deposited included sphalerite, galena, chalcopyrite, arsenopyrite, pyrargyrite, polybasite, argentite, electrum, quartz and carbonates. Subsequently some change in conditions caused certain of these minerals to be replaced by others also derived from the ascending solutions. The galena and to some extent sphalerite, quartz and polybasite of the earlier deposition became unstable and were replaced by argentite, chalcopyrite, carbonates or electrum. This sort of replacement has not been recognized often before, probably because the methods of microscopic study necessary have only recently been developed. Later, these primary ores were extensively modified by surface oxidizing waters with the development of a series of secondary minerals. There is evidence that such oxidation occurred at several different periods. W. E. F.

3. *Review of Geology and connected Sciences.*—The Société Géologique de Belgique, through its General Secretary, M. Paul Fourmarier at Liège, has recently announced its plan of conducting a geological review having the above title for abstracts of English and Scandinavian papers; while it would be known as the "Revue des Sciences minérales" for those of French, Italian, Spanish or Portuguese origin. The review would cover all the branches of geology and the sciences immediately related, giving concise summaries of published papers for which a reasonable honorarium would be allowed. It is intended to publish it monthly and in numbers of 32 pages or more for an annual subscription temporarily fixed at 45 francs.

## II. Miscellaneous Scientific Intelligence.

1. *The Whole Truth About Alcohol;* by George Elliot Flint. Pp. xii + 294. New York, 1919 (The Macmillan Co.).— "The Whole Truth About Alcohol" is a protest against national prohibition as a "measure for safeguarding a few hopeless inebriates, unquestionably defective," and in so doing "enormously inconveniencing as well as injuring the health and happiness of practically the entire population." In maintaining this hypothesis, Mr. Flint "tries not to be dogmatic, disagreeable, unjust or intolerant, while upholding the truth at any price and regardless of whom it may hurt." How consistently he carries out this well-intended purpose may be inferred from the statement (p. 157) that "it is true that the laboratories tell us that alcohol does not exhilarate; but we do not care for laboratories. We feel that we are exhilarated and that suffices."

Having discarded laboratories, Flint indulges in this form of reasoning (p. 146), "The cheap liquors (the most intoxicating) contain fusel-oil. It acts with many more times the intensity

of alcohol. Whence, it seems reasonable to suppose that the fusel-oil, rather than the alcohol contained in cheap whiskeys, is responsible for some cases at least of chronic alcoholism, particularly when we know that many inebriates prefer the cheap adulterated liquors, as being stronger than the better brands." Nor do the despised "laboratories" furnish authority for Mr. Flint's statement (p. 85) that "every particle of sugar taken into the human stomach is changed into alcohol, carbonic acid and water by the digestive ferments." It is needless to add further quotations to refute Dr. Jacobi's prefatory assertion that "the author's statements are based on scientific facts."

A. F. M.

2. *The Blind; their Condition and the Work being done for them in the United States;* by HENRY BEST, PH.D. Pp. xxviii, 763. New York (The Macmillan Co.).—Dr. Best has written a comprehensive social survey of the blind in the United States. Regarding them as certain components of the population, who demand classification and attention in the machinery of organization of the state, he examines the various problems that are raised by their presence in the body politic, and the several measures that have been put forth to deal therewith. In this way, he elucidates the attitude of the State toward the blind, as well at its duties to them; and the extent and form, the adequacy and correctness of the treatment accorded to them. Best concludes with a message of hope, grounded "in the increasingly determined efforts to reach and help all those who sit in darkness"; a hope that goes deeper still, looking to "the time when blindness itself shall be no more." A. F. M.

3. *Colloids in Biology and Medicine;* by H. BECHHOLD. Authorized translation from the second German edition, with notes and emendations by JESSE G. M. BULLOWA. Pp. xiv, 464. New York City, 1919 (D. Van Nostrand Company. Price $5.00).—The first part of this volume serves as an introduction to the study of colloids, those states of matter which have been endowed, in the recent development of science, with all manner of novel properties. Here the latter are discussed, and the manner of investigating them is pointed out. The living organism is considered as a colloid system which is called upon to explain many of the mysteries of secretion, metabolism, growth and development. At the present time any attempt of this sort must still be in good part a compilation of experimental observations and a formulation of bold hypotheses, as the author frankly admits. Nevertheless one must express surprise at such extreme statements as that, on p. 168, asserting: "Our foodstuffs consist entirely of colloids and their nutritive value is to be judged mainly from a colloid-chemical point of view." Many facts of unusual interest not commonly correlated have been brought together in the book. In part it is a story of long known phenomena expressed with the help of a new scientific vocabulary.

L. B. M.

4. *Aeronautics.*—A new review devoted to the entire sphere of aviation, documentary, historical and technical, is to be published by MM. Gauthier-Villars et Cie in Paris, with the collaboration of the French "Dirèction aéronautique militaire et maritíme." The plan is to give it an attractive form, fully illustrated and such as to appeal to the general public as well as to those immediately concerned.

5. *United States Coast and Geodetic Survey.*—It is announced that Major William Bowie of the division of geodesy in the Coast Survey received the degree of Doctor of Science at the recent Commencement of Trinity College at Hartford, Connecticut. He also represented the International Research Council at the meeting in Brussels which began on July 18.

## Obituary.

Lord Rayleigh, the celebrated English physicist, died on June 30 at his home, Terling Place, Witham, Essex.

John William Strutt, third Baron Rayleigh, was born on Nov. 12, 1842. He was graduated from Cambridge as senior wrangler in 1865 and for a time was a Fellow of Trinity College. In 1879 he succeeded Clerk Maxwell as Cavendish Professor of experimental physics at Cambridge and continued to occupy this chair until 1884 when he resigned. From 1887 to 1905 he was professor of natural philosophy in the Royal Institution—a post which required him to give only a few public lectures each year. He was secretary of the Royal Society from 1887 to 1896 and president from 1905 to 1908. In the latter year he became Chancellor of the University of Cambridge, and continued to hold this office until his death. He is succeeded in the title by his eldest son, the Hon. Robert John Strutt, who has followed in his father's footsteps as a physicist and has been for some years professor of physics in the Imperial College of Science, South Kensington.

Lord Rayleigh's first scientific paper was published in 1869 and for fifty years there has been no interruption in the steady flow of his contributions to science. There are altogether about 400 papers and, as J. J. Thomson says, "not one of these is commonplace, and there is not one which does not raise the level of our knowledge of its subject"; even in the last year of his life there appeared to be no falling off in his work in either quantity or quality. He was equally at home in mathematical and experimental investigations and, in both, his work was marked by extraordinary simplicity and directness of method. Most of his experimental work was done in a private laboratory in one of the wings of his country house and no physicist who visited it could fail to be astonished at the primitive equipment which was sufficient in Rayleigh's hands for work of the highest importance. A similar impression was made upon one when he

discussed work in which he was at the time engaged; it seemed so straightforward and natural that it was hard to realize that it might not have been equally well done by anybody.

The achievement by which Lord Rayleigh is best known to the general public is the discovery of argon, in the later stages of which he had the assistance of Sir William Ramsay. His treatise on The Theory of Sound has had no serious rival since its first publication in 1877; in all the laboratories and experimental stations which worked on the anti-submarine problem during the war, this work was constantly resorted to when difficulties were great, and it usually supplied either the complete solution or at least a suggestion as to the best mode of procedure.

Lord Rayleigh received all the honors and rewards which could fall to the lot of a man of science. He served on many boards and committees in the public interest with great advantage to his country. He was the first president of the Advisory Committee for Aeronautics—a body whose work before and during the war has been the chief factor in giving to Great Britain the pre-eminence in theoretical and applied aeronautics which she holds to-day. H. A. B.

Dr. Ernst Heinrich Haeckel, professor of zoology in the University of Jena, died at his home on August 9 in his eighty-sixth year. After his university studies at Würzburg, Berlin and Vienna, he devoted himself at first to medicine and settled in Berlin as a physician. The influence of Johannes Müller, the physiologist, led him, however, to take up the study of the lower forms of marine life. Later he became professor of zoology at Jena, a position which he held for about fifty years. He adopted the Darwinian theory as early as 1863 and from that time on his work and publications were largely devoted to the general subject of evolution. The theoretical side interested him particularly, and much of his work was in advance of his time, though subsequently accepted without question. He was an indefatigable worker and the list of his published works contains many of the first importance. Of his earlier publications may be noted his General Morphology (1866); The History of Natural Creation (1868); The Origin and Genealogy of the Human Race (1870); Anthropogeny (1874). In addition to these and numerous other general works, he published many special studies on the radiolarians, the sponges, on plankton, etc. Haeckel's strong individuality led him to develop his religious ideas in a work called "Monism"; his "Riddle of the Universe" is also on somewhat the same lines.

M. Paul Choffat, the distinguished geologist, died at Lisbon on June 6, 1919, after a long illness. He had been connected for many years with the Geological Survey of Portugal and the importance of its work in geology has been in large measure due to his ability and indefatigable industry. The general appreciation of the value of his work is testified to by the long list of Geological Societies of which he was a member.

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Joseph Barrell
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THE

# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

## JOSEPH BARRELL.

(1869–1919)

In the passing of Joseph Barrell, American geology has lost a leader, and one who promised to stand as high as the highest. His period of preparation and of storing up fundamental experience was back of him, and had he lived twenty years longer, it seems clear that he would have become the chief exponent in the subjects of geologic sedimentation, metamorphism, the geologic bearings of isostasy, and the genesis of the earth. T. C. Chamberlin writes: "We had come to look upon him as one of the most promising leaders in the deeper problems of earth science," and R. S. Woodward adds that "Geophysics has suffered a great loss." John M. Clarke says: "I feel that the loss to geological science in this country at this critical time is very great." And in the opinion of W. M. Davis: "The tragic news of Barrell's death is a truly overwhelming disaster for American geology. We place him foremost in our science."

Professor Barrell's death is a severe blow to his colleagues at Yale, following so soon after that of Professor Irving. Coming to us as a young man, we have seen Barrell grow into a maturity that exceeded our hopes and more than justified our choice of him to fill the chair of structural geology at this University. He was a power among us, and it was around him that our graduate courses in geology were built. Personally we are bereft of a friend whose place can not be filled,—one whose simplicity of nature and strength of character were unique. His wonderful fund of knowledge was

always gladly placed at our disposal, and his constructive criticism and fertility of suggestion have been the stimulus to more of our work than we shall ever realize. We rejoice that the privilege was ours of working with him, and in our hearts there will always remain the grateful memory of his inspiring personality.

Barrell's death occurred in New Haven, Connecticut, on May 4, 1919, after a week's illness with pneumonia and spinal meningitis. He leaves a wife, Lena Hopper Bailey, and four sons, Joseph, Herbert Bailey, William Colburn, and Richard Lull. Standing 5 feet 10·5 inches in height, of the blue-eyed Nordic type, with a full head of wavy light-brown hair, he was spare of build and yet of great muscular strength, the "strong man" of his class at Lehigh. Once seen, he was easily remembered, and he was quickly picked out in a crowd. This was due in part to his tall slender build, his long and awkward stride, and his confident bearing, but more especially to the strength of character reflected in his large features, particularly the wide mouth and long, narrow nose concave in profile. He prided himself on the longevity of his ancestors, and believed he also would attain to great age.

Modest and optimistic, with a strong independence of mind, he prized true worth highly, and was easily aroused to point out shams and errors, as he does tellingly in his review of "The Place of Origin of the Moon," in "Schaeberle and Geological Climates," and more especially in "Fair Play and Toleration in Criticism." Simple in attire and fond of simple living, his intellectual ideals were of the highest, and it was his plan that his sons should have the best of collegiate training. An omnivorous reader and a hard worker, he never tired of unravelling the intricacies of earth structure. Yet with all his own work, he was always ready to help his colleagues and students, and those who had problems to solve found him ever fertile in suggestion. No man ever had better developed the power of detachment from his own views than did Barrell. He could examine his conclusions from all angles. As Davis says, "He interested himself in thinking about how he thought, and tried to evaluate the results of his thinking. He was as careful and critical in this respect as he was fertile and ingenious in mental inventions." His writings show

him to be a successful teacher, in that he prepares the reader for what is to come and then sets forth the processes and principles that underlie the results sought for. This is why most of his studies are detailed and lengthy.

Finally, Barrell was above all a staunch American and a believer in American science, as may be seen in his paper on "Sources and Tendencies in American Geology," in which he expresses the conviction that our country will continue the "place of world leadership in geologic science" which it has maintained since 1890.

The name Barrell, spelled in many ways, had its origin among the ancient land-holding knights of Normandy, and by them was introduced into England in 1066 at the time of the battle of Hastings and William the Conqueror. The Barrells used to be numerous throughout the south of England, but are now confined mostly to Suffolk and Herefordshire. The first American of the name was George Barrell, a cooper by trade, who arrived at Boston from St. Michaels, South Elmham, Suffolk, in 1637, and died there in 1643. He became a freeman of the Boston parish on May 10, 1643, and owned a house on what is now the southeast side of Hanover Street between Elm and Washington. It is interesting to note here that at this time Massachusetts Colony had a population of about 16,000. In November, 1638, George Barrell bought his home for £28, and soon added to it about a half acre of land for which he paid £3 more. At this time he was one of the 246 land-owners of Boston. He had but two sons, and one of them, John, also a cooper by trade, married Mary, daughter of William Colburn, one of the twelve original founders of the colony. It is from this union that have sprung all of the American Barrells of colonial origin.

Until recently, the Barrells were in the main sea-going people, ship-owners and merchants. The second John Barrell was a mariner, and we learn that his son John was a well-educated man and a successful shipping merchant. Professor Barrell in his genealogy says of John III: "The hazards of travel and of residence in tropical lands, however, told severely upon their number, so that notwithstanding several large families of sons, his descendants bearing the name have remained few in number and widely scattered."

The most widely known and wealthiest was Joseph Barrell of Boston (1739/40-1804), after whom the subject of our sketch, his great-grandson, was named. He married three times and had twenty children. This Joseph Barrell was an original thinker and a good speaker and writer. He is said to have "early espoused and firmly maintained the cause of his country," and for a time represented the town of Boston in the State Legislature. He lived well, and it was in his splendid home that General Washington was entertained during his visit to Boston. He was also one of the group of men who fitted out the ship "Columbia" and sent her into the Pacific, where in 1792 her crew discovered the Columbia River. Later they purchased of the Indians the territory about this stream, and in this way began the colonization of what has since grown to be the northern Pacific states of the American Union.

The father of Professor Barrell, Henry Ferdinand, was born in New York City, October 3, 1833. His son says he "grew up with a strongly developed taste for books, for nature, and for life in the country." Henry Ferdinand's father bought him a farm near Warwick, Orange County, New York, and it was here that he met Elizabeth Wisner, whom he married on April 15, 1858. The Wisners, originally from Switzerland, had been land holders for 150 years and officers in the colonial and later wars. In 1864, Henry Ferdinand sold this farm and bought another of seventy acres at New Providence, New Jersey, and here from 1875 to 1895 he was chairman of the trustees of the public schools in which the subject of this biography received his primary education. He was also interested in the public school library, which later became the town library. He had nine children, of which Joseph was the fifth child and the fourth son.

Joseph was born at New Providence on December 15, 1869. As a child, he was more interested in books on natural history, astronomy, and history, than in literature. His mother, now eighty-one years old, and after whom he takes, relates in a personal communication that "Joseph was always a good son and student, and a great reader. When but a lad he would get down a volume of the Encyclopedia Britannica and sit for hours reading it. Nothing distracted his attention. When he was tired

from sitting in one position, he would turn around, put his book on the chair, kneel down, and continue to read. When he was about ten years old, his father bought him a planisphere, and often at night he would take it and a book on astronomy, along with a lantern, and then lie on his back gazing at the stars and so learning their names with the use of the planisphere. Joseph attended the public school in New Providence until he was sixteen years old. The school combined grammar and high school studies, but very few scholars went further than the lower grades. He had two excellent principals, Mr. J. W. Kenneday and Mr. W. C. Armstrong, both college-bred men, and they took him through the higher studies necessary for college entrance. His elder brother Robert was then at Lehigh, and we could not afford the expense of two boys at college at the same time, so Joseph passed the examination for a teacher's certificate and taught a small school near home during the school year 1886-1887. His salary was $200, but as he boarded at home without charge, he saved that amount towards college expenses. The following year he attended Stevens Preparatory School at Hoboken, New Jersey, and won a scholarship for Stevens Institute, but preferred a college course at Lehigh University, which he began in September, 1888. In those days tuition was free at Lehigh, and Joseph probably did not receive more than $1,000 from home during the four years he was an undergraduate, the rest he earned. At home from boyhood he helped with the farm work during vacations. We had a sulky plow which he rode. He early became interested in geology, and when plowing would stop the horses and examine every peculiar stone turned up. His father was a naturalist and early interested his children in birds, moths, butterflies, plants, and in fact everything pertaining to nature."

As we have seen, Barrell took up collegiate work at Lehigh in 1888, and was graduated four years later with high honors. In 1893 he received from the same University the E.M. degree, in 1897 its M.S., and in 1916 its honorary degree of Doctor of Science. In conferring this last degree, President Drinker said: "Joseph Barrell.—Distinguished scientist, a recognized leader in the study and teaching of geology, known and honored for his research and writing in the science of the

earth in which the earth's history has been written by a mighty hand,—Lehigh is proud of the record of this alumnus whose lifework has been so modestly yet so ably done, and through whose work his Alma Mater has been highly honored."

In a sketch of himself written for the twenty-fifth anniversary of his class at Lehigh, Barrell says that in 1893, when he received his second degree, "jobs were rare and I regarded myself as lucky in securing an instructorship at Lehigh in mining and metallurgy." This position he held for four years, teaching mechanical drawing, mining and metallurgical design, making shop visits to various metallurgical plants, and practicing mine surveying with students in the anthracite mines. "Teaching is always better training for the teacher than for the taught. After the reorganization of the work in the first year I found some free time. The summers were put in in gaining experience, parts of the winters were employed in studying geology and practical astronomy, for which Lehigh gave me the degree of M.S. in 1897." His thesis for this degree is 419 pages long, and is entitled "The Geological History of the Archean Highlands of New Jersey, including their Extension in New York and Pennsylvania."

In 1898, Professor E. H. Williams, Jr., then of Lehigh, contemplating a division of his work, got the university to consent to hold vacant for two years the position of assistant professor of geology if Barrell would spend that time at Yale in advanced work. Barrell says this opportunity "was a most generous one on the part of Professor Williams. I spent the following two collegiate years at Yale and the summers working in Montana for the U. S. Geological Survey in general and mining geology. . . . In 1900 Yale gave me the degree of Ph.D., and thus a mining and metallurgical education, combined with a panic year on leaving college, had led logically into a career as a geologist. The initial engineering education and the experience of the eight years following 1892 formed the broad and solid base on which the following work has been built."

For three years after 1900, Barrell taught geology at Lehigh, with biology as a side issue. In December, 1902, he was married at Bethlehem, Pennsylvania, to Miss Bailey, and the three summer months of the year pre-

ceding were spent in Europe with Professors Herbert E. Gregory and Charles H. Warren, travelling "by foot, by bicycle, and by third-class trains, the object being to see the countries and study geology rather than to do sightseeing in the cities. . . . Another turn in the wheel of fate called me in 1903 to Yale." In 1908 he was promoted to a professorship and, as he says, was "fixed as a staid professor. The position offers opportunity for three kinds of work, one-third of the time teaching geology to undergraduates in Yale College, one-third teaching in the Graduate School future professional geologists, and one-third of the year for research. The latter gives the most visible measure of work accomplished."

Barrell was a member of the Sigma Xi honorary scientific society, and president of the Yale Chapter in 1911-1912. He was also elected to the Phi Beta Kappa chapter of the same University. He was a fellow of the Geological Society of America, the Paleontological Society, and the American Association for the Advancement of Science, and a member of the American Academy of Arts and Sciences. Only a few days before his death, there came to him the news of the highest honor that can be given to an American scientist, election to the National Academy of Sciences.

A man of science, and especially one deeply interested in generalizations, should be endowed with imagination under restraint. Barrell had a great deal of this quality, and loved to speculate under the limitations of "multiple hypotheses." It was a pleasure to listen to him telling his children about gnomes and elves, and occasionally, as in his "Central Connecticut in the Geologic Past," or "A Vision of Yale in 6010," he allowed himself flights of figurative writing." The most humorous of these only too rare instances appears in a discussion of a classification of marine deposits in the *Bulletin* of the Geological Society of America. Here he is presenting the view that materials foreign to the sea may be rafted there by trees and ice. And then he digresses into this: Man has become "an important geological agent. The oxidized and inorganic débris which he throws overboard from ships must already mark out the steamer lanes, especially, across the abyssal ocean bottoms. The unalterable materials which he con-

tributes most abundantly to the deposits of the sea are coal ashes, broken dishes, and bottles. These are being permanently incorporated in the crust. . . . The name being recorded most widely and indelibly on the earth at the present time is the name of him who made Milwaukee famous."

As a teacher, Barrell was by far the most effective with graduate students and geologists. The former were enthusiastic in their praises of their instructor in dynamical and structural geology, for he gave them much that was not to be found in books. He succeeded well with the undergraduates, but many of them found him exacting in detail, and some would say that he was "too statistical," referring to the detail that the first-year man in college geology does not properly appreciate. On the other hand, one of his graduate students, Carl O. Dunbar, writes: "I shall prize even more than ever those golden days when I sat before him watching the twinkle in his eyes that so often foreshadowed a brilliant thought that was taking shape behind them. His image will always be my conception of the thinker." Another, Walter A. Bell, says: "There was our admiration and appreciation of his keen analytical mind which was balanced on the other hand by the breadth of his judgment and the depth of his fertile imagination. But there was more than this—a more elusive personal charm that bound us to him. He stimulated the mind as cool mountain breezes and mountain heights stimulate the senses. You rarely sensed this in his writings, but always in conversation, in the class room, or wherever you came into personal touch with his intellectual vitality."

As a lecturer, Barrell was often called on by universities other than Yale. In 1912 he gave a series of five lectures at the University of Illinois, dealing with "The Bearing of Geology on Man's Place in Nature," and "The Measurements of Geologic Time." In 1914 he gave a course of three Sigma Xi lectures at the Universities of Missouri and Kansas. At Columbia he gave two years later six lectures on isostasy, and at New Haven he presented before both the Sigma Xi and Phi Beta Kappa societies his interesting talk on "The Habitability of Worlds."

As a geologic expert, Barrell testified in a number

of lawsuits, the chief ones being in relation to the Utah Apex Mining Company of Bingham, Utah, the Federal Mining and Smelting Company of Shoshone County, Idaho, and the Hudson Blue Stone Company of Kingston, New York. He made a good witness, not only because of his extensive knowledge of mining and geology, but more especially because his testimony on the stand could not be shaken by opposing counsel.

An analysis of Barrell's writings shows that he progressed from simpler field relations to the most complex of geologic problems. It is also clear that his best results were obtained through generalizing from the publications of others. He loved to assemble the field and laboratory observations made by other workers in comparison with his own, and then, subjecting them to the test of multiple hypotheses, ascertain the probable explanation of the facts under study.

Barrell's first publications, in 1899 and 1900, deal with mining, but since 1901 nearly all of them have had to do with geology. His bibliography, if completed in detail, would take note of about 150 notices and reviews of books, nearly all of which appeared in this Journal. Of these nineteen contain original matter, and are therefore included in the bibliography. Nearly all deal with isostasy, the origin of the earth, and metamorphism, subjects most familiar to Barrell. When he set himself to write a review of a book, he produced a lucid analysis, with discussions of the conclusion attained by the author. Of short papers and longer memoirs, there are fifty-one, totalling nearly 1,700 pages. In addition, there are eight manuscripts in a more or less finished condition, and some of these, after they have been edited by his colleagues, will probably be printed within a year.

Barrell's earliest papers, as has been said, relate to mine surveys. Then he took up areal geology, studies of the relations of intrusive masses, and their alteration and mineralization of the invaded geologic formations. After some years as an instructor of graduate students in dynamic geology, his ideas in regard to processes of erosion, sedimentation, the formation of deltas, and the discerning of ancient climates in the sediments took form, and it is on these subjects that he next wrote. Nearly one-fourth of his publications fol-

low these lines. He also did much to build up the science of paleoclimatology, and in paleogeography he established principles for discerning the shore-lines of the seas and the extent and elevation of the ancient lands that were furnishing the sediments. Had he lived longer, he would have done much more, and an unusual opportunity for stimulating others would have come to him as chairman of the new Committee on Sedimentation in the National Research Council.

Probably Barrell's most philosophic and most difficult work relates to isostasy. About one-sixth of his publications have to do with the strength of the earth's crust. He states that "The larger features of the earth's surface are sustained in solid flotation," and "the subcrustal shell is subjected to but little else than hydrostatic pressure." Isostatic balance is, however, not everywhere in adjustment, for "the outer crust is very strong, capable of supporting individual mountains, limited mountain ranges, and erosion features of corresponding magnitude."

The length of geologic time was another problem that deeply interested Barrell. In his "Rhythms and the Measurements of Geologic Time," he came to the conclusion that through the rhythmic oscillations of the terrestrial processes which the earth has undergone, its age is many times greater than even geologists in general have imagined—in fact, that it is of the order of about 1,500 million years.

Another line of research which occupied Barrell was the origin and genesis of the earth, and here he extended in modified form the Chamberlin-Moulton planetesimal hypothesis, i. e., that the planets and their moons arose out of the sun during a time of induced tidal disruption. Some of his best work was to develop along this line.

While an undergraduate student at Lehigh, he became interested in the physiography of the highlands of New Jersey and Pennsylvania. He had studied Davis's works, but on account of the peculiarities of the rivers that flow through the ridges and the many wind-gaps in the region with which he was familiar, he concluded that much of the area must have been beneath the sea and been covered by sedimentary deposits. This was in opposition to the prevalent view that the present rivers were incised in the "Cretaceous peneplain."

His views were formulated for the first time in his Lehigh thesis of 1897, but it was not until 1913 that he presented the matter in more mature form before the Geological Society of America. The supposed Mesozoic peneplain of southern New England was in reality, he said, "stairlike or terraced in its character, facing the sea," and of marine origin. It was this study that was absorbing him most in recent years, and his *magnum opus* on it was to appear a few years hence. There is a manuscript dealing with it, but this represents only a small part of what the final publication was intended to be.

As Barrell also taught biology at Lehigh and historical geology at Yale, it was natural that he should be interested in paleontology. This side of his activity is little known away from Yale, but his colleagues there knew of his deep interest and knowledge in this line. Animal structures interested him as mechanisms, and he tried to see the operation of the laws of mechanics in them. And through his insight into paleoclimatology he tried to discern the operation of the changing environment as the most important cause of organic evolution.

Finally, in one of his last papers, "Sources and Tendencies in American Geology," he states that "geologic research in the past generation has been passing out of the qualitative stage and has partaken notably of the quantitative character." In this great advance he names Dana, Hall, Marsh, Cope, Powell, Dutton, Gilbert, Davis, Chamberlin, Van Hise, and Irving as those who will stand out as the great leaders of the earth sciences in America.

## Review of the Writings of Joseph Barrell.

### *Mining Engineering.*

Barrell's first experience as a mining engineer was in 1894, while with the engineering corps of the Lehigh Valley Coal Company, at Wilkesbarre, Pennsylvania. In June, 1897, he joined the engineering corps of the Butte & Boston Mining Company of Butte, Montana, and worked with them and the Boston & Montana Company for over a year. Of this work he says: "The initial wages of three dollars a day seemed a recogni-

tion of some degree of ability until I learned that I was indebted to the miners' union which fixed the minimum wage for laborers underground at that figure. The work was interesting and involved difficult problems in the plumbing of crooked shafts, and the measurements of amounts of ore extracted from old workings." These experiences led to his publishing in *Mines and Minerals* during 1899 and 1900 a series of five papers which he wrote while at Yale studying for the doctor's degree. They have to do with the methods and errors of mine surveying, instrumental errors, methods of keeping stope books, and the choice of survey instruments. The papers abound in mathematics and in diagrams, and thus foreshadow two of Barrell's future tendencies in geology.

### *Regional Geology and Metamorphism.*

During the summer months of 1899, Barrell was field assistant to W. H. Weed of the U. S. Geological Survey, mapping the ore-bearing formations of the Elkhorn Mining district of Montana. This work, Barrell states, was done alone, much of it on horseback, in the mountainous region between Butte and Helena. It involved a study of the great successive intrusions of molten rock which in the early Tertiary had broken up the crust, and brought in the wealth of gold, silver, and copper. The first result of these field studies was the publication of the "Geology and Ore Deposits of the Elkhorn Mining District," by W. H. Weed, with an "Appendix on the Microscopical Petrography of the District," by Joseph Barrell.

Having done this field work, Barrell returned to Yale in the autumn of 1899 and made his results the basis of a dissertation for the doctorate. With the guidance of Professor L. V. Pirsson, he made an elaborate petrographic study of the rocks, and these results, along with the geology of the Elkhorn area, formed the basis of his dissertation, which is entitled "The Geology of the Elkhorn Mining District."

As a result of the Elkhorn work, Barrell in his dissertation wrote a chapter on "The Physical Effects of Contact Metamorphism." This is also the title of an article published in this Journal in 1902, and abstracted from the chapter referred to. In this paper Barrell

discusses the changes of mass and volume through metamorphism, and states, among other things, that the shrinkage in rock of certain compositions may be "from 25 to 50 per cent in volume, attended with the evolution of great quantities of gases which at surface pressures and temperatures would amount to several hundred times the volume of the original sediments."

Metamorphism always remained one of Barrell's foremost lines of work, and as late as 1914 he wrote a manuscript entitled "Relations of Subjacent Igneous Invasions to Regional Metamorphism." It is hoped that this paper may be printed in 1920.

In the summer of 1900, Barrell was again employed by the U. S. Geological Survey in a two months' reconnaissance of the surface geology of the Deerlodge region of Montana and of the underground geology of Butte. The next year he began, again under the direction of Mr. Weed, a three months' geological survey of the surface and underground geology of the Marysville mining district, Montana. His results were worked out at Yale and published as "Geology of the Marysville Mining District, Montana: a Study of Igneous Intrusions and Contact Metamorphism." This region was one of the noted gold-producing centers of Montana, and the mines were situated around the margins of the irregular Marysville bathylith of quartz diorite, whose surface exposure is from half a mile to one and a half miles broad and two and one-half miles long. This invasion of igneous rock was primarily the cause of the location of the mineral wealth in this district. It is "but 6 miles at its nearest point from the exposed surface of the far greater Boulder bathylith, a granitic mass which is petrographically a quartz monzonite in normal composition. The Boulder bathylith possesses a general rudely rectangular form, occupying about 60 miles in latitude by about 35 in longitude, and holds within its confines the mining city of Butte, from which for many years past has poured a flood of silver and a quarter of the world's production of copper. Other smaller mining centers also lie within this large granitic area, while such important ore deposits as those of Elkhorn and Unionville, south of Helena, have been found about its margin."

In regard to the Marysville report, which has now

become one of the classics in geology, Pirsson says of it in this Journal: "The special character of the work lies in the detailed investigation of the bathylithic body, of the method of its intrusion, of its form, and of its relations to the surrounding rock masses both past and present." The intrusion Barrell could not explain by the accepted methods, and did so by a new theory, that of magmatic stoping. Daly, in his book "Igneous Rocks and their Origin," states that "It was in the Cordilleran region, at Marysville, Montana, that Barrell independently invented the stoping theory of magmatic emplacement."

Because of the large scale on which the Marysville and Boulder bathyliths are exposed, and because of the forceful presentation of the field relations and the clearness of Barrell's inferences therefrom, Suess in his great work, "The Face of the Earth," was led to say that the Marysville report is "one of the most instructive works produced in modern times" connecting granitic invasions with volcanoes.

The interesting and popularly written pamphlet, "Central Connecticut in the Geologic Past," visualizes the major events in the geologic history of the state. It is illustrated by a series of eight highly instructive structure sections drawn by Barrell himself. These sections show clearly Barrell's faculty for picturing his thoughts; not infrequently he would express an idea in graphic form before he put it in writing.

*Erosion, Sedimentation, and Climatology.*

The writer of this biography joined the Geological Department of Yale University in 1904, and at that time became acquainted with Barrell, then an assistant professor. As both of us had our offices in the Peabody Museum, we saw much of each other, and often our discussions had to do with sedimentation. I would relate to him the varied phenomena which I had seen in the field and the distribution of the formations, and he would try to decipher their processes of accumulation. Then in 1905, after I had listened to his course of about twelve lectures, I urged him to publish his views, especially as to the depth of water and the climate suggested by the nature of the sediments. In the following year he

published a series of three papers on the "Relative Geological Importance of Continental, Littoral and Marine Sedimentation" in the *Journal of Geology*.

In these papers he sets forth a quantitative view as to the relative importance geologically of these three types of sediments, and the criteria for separating them. It is a study of facts already assembled in the geologic literature, but always from their original sources. Further, it is the application of changing and cyclic geographies in their relation to stratigraphy, with the emphasis on the fact that by no means all of the sediments are of marine origin. Among other things he develops the criteria for discerning subaërial delta deposits, and he shows that such deposits attain their greatest development after epochs of mountain-making unaccompanied by notable uplift of the continental platforms. He also emphasizes the cyclic relations between continental and marine sedimentation in geologic history. The wide and cyclic significance of mud-cracks in association with other features indicating flood-plain deposits is discussed at length and applied to the interpretation of Proterozoic deposits in Montana and the Grand Canyon of the Colorado.

The significance of desert deposits becomes very striking when one notes that one-fifth of the present land surface is desert tracts. And Barrell estimates that the subaërial deposits of piedmont waste, of continental basins, and of deltas cover about one-tenth of the emerged continental surfaces. Adding these "to the estimate of the deposits of arid climates would give a fifth of the land surface as mantled by continental formations." The lands in the course of the geological ages are, however, warped and elevated into mountain ranges, so that the geological record "should show a far less proportion of these and superficial land deposits." On the other hand, basin and delta deposits should be quantitatively as great as those laid down upon the floor of the epeiric seas.

Having developed the principles of sedimentation for continental and shallow-water marine deposits, Barrell applies them in 1907 to a late Mississippian formation in the paper "Origin and Significance of the Mauch Chunk Shale." Here are presented the significant facts regarding this formation, gathered from the literature

and from personal observation. He concludes that "In the anthracite region, more surely in the southeastern and eastern portions, the whole formation [which is about 3,000 feet thick], from top to bottom, was a subaërial [delta] deposit laid down under a semiarid climate." The nearest approach to-day to a similar area is that of the highly arid Punjab region near the base of the Himalayas, and of the lower plains of the Indus River. "These comparisons, while not intended to convey the idea that the Appalachians were ever of Himalayan magnitude, are suggestive of a more massive range of mountains and a wider land area to the eastward of the Pennsylvanian geosyncline than is customarily thought of as existing in Upper Devonian and Carboniferous times."

Having seen much of the Carboniferous of eastern Pennsylvania, Barrell had asked himself, "To what extent have the tectonic movements and climatic variations caused the great contrasts seen here in the Lower and Upper Carboniferous formations?" To solve this problem, he took up in detail the principles that have to do with the relations between modern climate and terrestrial deposits, and published his conclusions in "Relations between Climate and Terrestrial Deposits." He writes: "The environment of the lands may be classified into three fundamental and independent factors—the relations to the surrounding seas, the topography which forms their surfaces, and the climates which envelope them; each of major importance in controlling the character of the lands." Fundamental are the relations of continental fluviatile deposits to the climates, and they may be successfully used in determining those of the geologic past. "This is exclusive of the significance of salt and gypsum deposits on the one hand or of glacial deposits on the other, which are of course universally recognized, but these are the marks of climatic extremes."

The first part of the paper under review has to do with the relations of sediments to regions of erosion. It deals with the relation of physiography to erosion and the consequent supply of waste as sediments to the formations. Then he takes up the relations of sediments to regions of deposition, and finally the relations of climate to fluviatile transportation. These parts

lead to the conclusion that "Climate is a factor comparable to disturbances of the crust or movements of the shore-line in determining the nature and the variations in the stratified rocks of continental or offshore origin, thus playing a part of large, though but little appreciated, importance in the making of the stratigraphical record."

Along with many other things, Barrell finds that "While the varying powers of erosion and transportation are delicate stratigraphic indicators of *climatic fluctuations,* the chemical and organic control accompanying the deposition are the more secure indicators of the *average climatic conditions.*"

Finally, what was the origin, environment, and significance of the conglomerate and sandstone formations intercalated between others of different nature? His answer is that these coarse materials have three origins: First, marine conglomerates and sandstones; second, tectonic conglomerates and sandstones; third, climatic conglomerates and sandstones.

"Changes in volume of ocean waters, earth movements, and atmospheric activities are the three mixed and fundamental causes by which the three classes of deposits become possible, but the records which they embody are largely distinct and independent. By separating conglomerates and sandstones into these three classes, the sedimentary rocks, therefore, present a threefold record, the marine conglomerates giving that of the variable relations of land and sea; the tectonic conglomerates, the record of variable vertical uplifts; the climatic conglomerates, the record of variable temperature and rainfall."

Barrell next took up for study "Some Distinctions between Marine and Terrestrial Conglomerates," the gist of which he presented before the Geological Society of America in 1908. Of this study there is printed only a half-page abstract, but back of it lies over 200 pages of manuscript completely rewritten in August, 1910, and entitled "Marine and Terrestrial Conglomerates." It is hoped that this paper may be printed before the close of 1920. In the abstract he states that "The truly terrestrial forces produce vastly more gravel, spread it far more widely, and provide more opportunities for deposition than do the forces of the littoral zone."

Marine conglomerates are "limited to considerably less than 100 feet in thickness," while terrestrial ones are "frequently measured in hundreds and occasionally in thousands of feet."

Having finished the paper on conglomerates, Barrell now sought out a thick and unfossiliferous conglomerate-sandstone series whose age relations were obscure. Such a series he found in the southern Appalachians, and upon this he made another study that remains unpublished. The conglomerates, sandstones, and slates of the Ocoee and Chilhowie groups of Tennessee, North Carolina, and Alabama, have long been a stumbling block in classification, because it is only near the top of the long series that fossils have been found. On the basis of these fossils, Keith finally referred all of the Ocoee and Chilhowie to the Lower Cambrian. Barrell discusses the many formations of this series, aggregating between 9,000 and 13,000 feet in depth, and concludes that the lower part, with a maximum thickness of 7,500 feet, is of terrestrial origin. The middle formations, with a thickness of 3,400 feet, are at least in part a terrestrial deposit, though a part is probably marine. The remaining 2,700 feet are entirely of marine origin.

In 1912, Barrell, in continuation of his studies of sedimentary formations, published the paper entitled "Criteria for the Recognition of Ancient Delta Deposits." He defines a delta "as a deposit partly subaërial built by a river into or against a body of permanent water." This study concerns the detailed structures of deltas and the physiography of the land that furnished the detritus. It is a difficult study because of the great variability in the extent of deltas, the marked variation in the character of their sediments, the size and streaming power of the river or rivers that bring the material, and finally the wide variation in the wave and streaming forces of the water body and the depth of the water in which and in front of which the deltas are laid down.

The underlying principle of this work is the cyclic one. The erosion by rivers "passes through its cycle of youth, maturity, and age, and the characteristics of the river valley and river waste change with the distance from the headwaters and with the progress of the erosion cycle. There must also be a delta cycle, and it

is to be expected that the size of the delta and the character of its deposits will depend not only on the original relation of the other physiographic elements of the continent, but on the progress of the cycle of erosion on the one hand and of the cycle of deposition on the other."

In 1913-1914 followed the application of the criteria of the previous paper to an ancient or fossil delta in the study entitled "The Upper Devonian Delta of the Appalachian Geosyncline." This is one of Barrell's best pieces of work, and a very philosophic one, for it brings out the relations of the Appalachian delta, both to the interior sea and to the extensive eastern land Appalachia and the Atlantic Ocean beyond. This extensive delta system began to form in the Middle Devonian and ceased in early Mississippian time. Its sedimentary volume Barrell computes at about 16,500 cubic miles for the Middle Devonian and 63,000 cubic miles for Upper Devonian time. "This is an impressive measure of the volume of the adjacent land which was eroded in Upper Devonian times. But it is a minimum measure, since that part of the rocks which was taken into solution was carried farther away, and of the mechanical sediments it represents only that part which was carried westward into the trap of the geosyncline."

This great amount of Upper Devonian sediments implies a much greater Appalachia than is usually assumed. In elevation it must have exceeded the present Sierra Nevadas. Barrell states that this old land "was not confined to the limits of the present continental shelf. . . . The foundations of Appalachia are buried some thousands of feet beneath it, extend beyond it, and doubtless slope gradually for an unknown distance toward and beneath the basin of the Atlantic," where is now deep ocean. "In Upper Devonian times the mountains which rose above these foundations stood on the eastern side of the Appalachian system." Accordingly, great parts of eastern Appalachia have been fragmented and sunk into the depths of the Atlantic during Mesozoic time.

As early as 1905, Barrell began to ask himself, "What were the geographic and climatic conditions which controlled the nature of the Old Red Sandstone deposits?" In 1907 he wrote out his views but withheld them from

printing, thinking that he and the present writer would find means of visiting Scotland. As this opportunity did not come, he presented his views in 1916 in the paper "Dominantly Fluviatile Origin under Seasonal Rainfall of the Old Red Sandstone." A copy of this was sent to Professor T. G. Bonney of University College, Cambridge, England, and his letter of thanks to Barrell opened with the word "Eureka." Truly we have here the correct explanation of the origin of the Old Red Sandstone.

"The central conclusion reached in this paper is that the Old Red Sandstone formations were not deposited in lakes and estuaries, nor are they of desert origin." They are "river deposits accumulated in intermontane basins," "exposed to air in times of drought," and "similar to the basin deposits of the western United States laid down in the Tertiary period between the growing ranges of the Cordillera." "The Great Valley of California may therefore in the present epoch, both in physiography and in climate, be cited as a striking illustration of the nature of the Old Red Sandstone basins."

*Physiography.*

Previous to 1908, most physiographers held that the flat sky-line of the land seen in the southern part of the New England states represented a Cretaceous peneplain uplifted in early Tertiary time, but in 1912 Barrell put forward a view long entertained by him, namely, that not only was this plain not of Cretaceous age, nor even of subaërial erosion, but rather that the supposed plain is a series of seven sea-cut terraces, the result of wave planation, made at different times during the late Mesozoic and Cenozoic eras. This fundamental change in interpretation was presented before the Geological Society of America in 1912 under the two titles "Piedmont Terraces of the northern Appalachians and their Mode of Origin," and "Post-Jurassic History of the Northern Appalachians." Since then from time to time Barrell had been working on this alternating series of uplifts and strand-lines, and most of the time in the laboratory with topographic maps. On October 16, 1915, he guided the New England Intercollegiate Geological Excursion across four of these terraces, made since Mio-

cene time, from New Haven northwest to Litchfield, a distance of about 35 miles. It was a memorable and proud day for the writer to see Professor Barrell presenting his views and defending them against all comers before a more or less dissenting audience, among which were W. M. Davis, R. A. Daly, W. W. Atwood, and D. W. Johnson. If these gentlemen were not at that time convinced, they were at least unable to make headway against the leader of the party.

It was Barrell's intention to spend some of the summer of 1919 and most of that of 1920 in the field to try out in critical places between Virginia on the south and Rhode Island on the northeast what he had observed first about Lehigh and later in Connecticut. This plan is now broken, but he has left a long manuscript treating of these terraces, and a great mass of annotated folios and generalized drawings showing the various facets in their present eroded condition. This manuscript is now being edited by H. H. Robinson, and will be published in the course of the year.

### *Rhythms and Geologic Time.*

Barrell was one of the participants in a symposium on the interpretation of sedimentary rocks at the Albany meeting of the Geological Society of America in 1916. Here he presented a part, but only the smallest part, of a study on "Rhythms and the Measurements of Geologic Time." This is his most important study, and will long remain a source of information and stimulation to research along several lines of philosophical thought.

He had long been attracted by the cycles of sedimentation, and now he states that "Nature vibrates with rhythms, climatic and diastrophic." The viewpoint of the six parts of the study is geological, though the evidence furnished by radio-activity is thoroughly reviewed. Part I treats of the rhythms in denudation, and shows that "erosion is essentially a pulsatory process," and that "a single rhythm is the erosion cycle; and small partial cycles are superimposed on larger." Here then is developed the hypothesis of compound rhythms. This part leads to the conclusion that the present rate of denudation is high, and "very much greater than the mean of geologic time." Part II deals with rhythms

in sedimentation, and shows that sedimentation is "not a continuous process, even during a stage of crustal depression." Therefore the stratigraphic record is replete with "breaks" of varying time lengths, the non-seeable greater disconformities and the lesser but more numerous diastems.

Part III treats of the estimates of time based on geologic processes, on erosion, sedimentation, hypothesis of compound rhythms, amount of oceanic salt, and on the loss of primal heat. In this presentation we get a more adequate idea of the quantitative lengthening of geologic time. "Measurements of time based on radioactivity" is the subject of Part IV, which is a worthy associate of A. Holmes's "Radioactivity and the Measurement of Geological Time," published in 1915. Finally, in Part VI, "Convergence of Evidence on Geologic Time and its Bearings," the geological and physical arguments are bound together into a unity, resulting in the conclusion that at least 550 million, and a maximum of 700 million years have elapsed since the beginning of the Cambrian. This is, moreover, less than one-half of geologic time, for the Laurentian or post-Ladogian granites, the oldest great invasions of igneous magmas into vast thicknesses of sedimentary formations, have an age as great as 1,400 million years. The earth is, therefore, much older than even this great figure.

Harlow Shapley, the astronomer, accepts Barrell's geologic time estimates, and says: "We may study the stars, indeed, with the aid of fossils in terrestrial rocks, and acquire knowledge of atomic structure from the climates of Precambrian times." "In the growth of our concepts of the age of the earth, Barrell's discussion is likely to mark an epoch because of its consistent carefulness, its great expansion of geologic time beyond the commonly accepted limits, and its decided rebellion against the stringent limitations set by Kelvin and later physicists."

*Isostasy.*

It is interesting to note Barrell's early independence of mind and his love for quantitative studies and philosophical analyses in geology, as shown in his notice in this Journal in 1904 of T. M. Reade's "Evolution of Earth Structure." In August, 1906, he notices, also in

this Journal, J. F. Hayford's paper, "The Geodetic Evidence of Isostasy," and gives a brief historical review of the place of this subject in geological literature and of the problems upon which it bears.

In 1914, Barrell was led to study the theories leading to the conclusion that the poles of the earth are not fixed. Astronomers and some geologists are opposed to the theory of polar wanderings, but students of ancient climates and of the geographical distribution of floras and faunas have been adherents to this view. In his "Status of Hypotheses of Polar Wanderings," Barrell states: "From these considerations it is seen that closer examination tends to cut down more and more even those moderate limits of polar migration set by [the mathematician] Darwin. It would appear that the assumption of polar wandering as a cause of climatic change and organic migrations is as gratuitous as an assumption of a changing earth orbit in defiance of the laws of celestial mechanics."

During the years 1914 and 1915, Barrell published in the *Journal of Geology* a series of eight papers that were later collected and bound in one volume under the title "The Strength of the Earth's Crust." This work at once placed him high among the geodesists. Arthur Holmes writes of it as a "remarkable series of papers, which is worthy of the most careful study," and "constitutes a valuable and stimulating contribution to terrestrial dynamics." L. V. Pirsson says: "They constitute probably the most serious and profound discussion, which has yet been attempted, of the facts which are known and of the theories which have been deduced from them, concerning the strength of the earth's outer shell."

The first part of this series of articles treats of the geologic tests of the limits of strength. In Parts II and III is discussed the "Regional Distribution and Influence of Variable Rate of Isostatic Compensation." Part IV deals with the "Heterogeneity and Rigidity of the Crust as Measured by Departures from Isostasy," while Part V is on the "Depth of Masses producing Gravity Anomalies and Deflection Residuals." Part VI is devoted to the "Relations of Isostatic Movements to a Sphere of Weakness—the Asthenosphere," and Part VII to "Variation of Strength with Depth, as Shown

by the Nature of Departures from Isostasy." The final part has to do with the "Physical Conditions Controlling the Nature of the Lithosphere and Asthenosphere." It is evident that Barrell intended to publish other parts in this series, for we have found among his papers the manuscript for Part IX on the "Problems involved in the Temperature Gradient conforming to the Curve of Crustal Strength." During the winter of 1914-1915 he wrote still another manuscript that appears also to have been intended for this series; it is entitled "Relations of Pleistocene Warping to Strength of Crust." These two articles we have been advised not to publish in their present form; they will, however, be of service to the Geological Department of Yale University.

Pirsson says of these papers: Barrell "finds that the crust is very strong when measured by its capacity to support great deltas, mountain ranges or large internal loads due to variations in density not in accord with topography, while on the other hand the altitudes of the continents as a whole or in large sections show nearly perfect isostasy. The maintenance of such isostatic conditions through geologic time, in spite of opposing geologic activities, is held to imply the existence of a zone of undertow below the zone of compensation, which is both thick and weak to shearing stresses. Geologically, such a zone, called the asthenosphere—the shell of weakness—must have important bearings, which are treated in the later portions of the work."

With this biography are printed two other papers on isostasy written by Barrell for this Journal, the longer one having been completed shortly before his death. This paper was written in answer to certain recent adverse criticism of the theory. Here Barrell gives an easily readable outline of the theory of isostasy, a long presentation of the problems connected with it, and his final interpretation of the isostatic data of India, the birthplace of the hypothesis.

### *Genesis of the Earth.*

In 1907, Barrell was aroused into criticism by Professor W. H. Pickering's paper, "The Place of Origin of the Moon." This place the latter thought to be the Pacific Ocean, thus giving rise to that basin, an hypoth-

esis first stated, but cautiously, by Osmund Fisher in 1882. Barrell quickly demonstrated that oceanic basins could not have arisen in this way.

Barrell left a long manuscript on the genesis of the earth that it is hoped may be published in book form along with some of his other geologic essays. As an instructor of historical geology, and because of questionings by the writer of this biography, but more especially through the writings of Chamberlin, he was gradually led to delve more and more deeply into this subject. Then in 1916 appeared Chamberlin's book, "The Origin of the Earth," a work "which has long been desired by geologists as well as other scientists," and as Barrell wrote a critical review of it in *Science,* those who wish may obtain from this review some of the points in which he differs from Chamberlin. Another place where he presents his modified views of the planetesimal hypothesis is in the book entitled "The Evolution of the Earth and its Inhabitants," 1918, to which he contributed the first chapter.

*Paleontology and Evolution.*

Since the days at Lehigh when Barrell taught zoology as well as geology, he had remained deeply interested in the more fundamental problems of paleontology and zoology. He never was much concerned with species and genera, however, or with classification, but rather with the bony mechanism of vertebrates, evolution, and the environmental causes that bring about the sweeping changes in organisms.

Through the determining of ancient climates as discerned in the nature of the geologic formations, and more especially in the continental deposits of the Silurian and Devonian, Barrell's interest was directed to an hypothesis first set forth by Chamberlin, as to the first habitats of fishes and the origin of lungs and limbs in dipnoans and amphibians. His ideas on these subjects culminated in 1916 in his "Influence of Silurian-Devonian Climates on the Rise of Air-breathing Vertebrates." The problems he seeks to answer are two: "first, as to the environment in which fishes develop; second, the changes in the environment and the associated organic responses which brought forth amphibians from fishes. It is the

solution of the second problem which is here especially sought.''

''It is shown to be probable that fishes arose in land waters. As such they constituted primarily a river fauna.'' It is in the Middle Devonian that ''the fishes first really begin to conquer the ocean and its former rulers.'' On the other hand, in the fresh waters of this time fishes abounded in greater variety than in the seas. In the Upper Devonian, crossopterygian fishes had risen to a dominant place, and they were adapted to live in warm climates marked by alternation of wet and dry seasons. It was this environment that gave rise to the amphibians. ''The warm and stagnant waters of the dry season compelled those fishes which should survive to make larger and larger use of air.''

''The evidence is regarded as strong that the air-bladder was originally developed as a supplemental breathing organ, although in modern fishes it has been mostly diverted to other uses.'' Barrell also quotes this significant passage from W. D. Matthew: ''The evolution of land life in adaptation to recurrent periods of aridity supplies a satisfactory background of cause for the whole evolution of the higher vertebrates.'' And he adds: ''The rise of amphibians from river fishes in an epoch of semiaridity was one of the major steps in the evolution of man.'' ''Climatic oscillation is a major ulterior factor in evolution.''

The study of the natural environment as recorded in the sediments that also entombed the fossils led naturally to the work entitled ''Probable Relations of Climatic Change to the Origin of the Tertiary Ape-Man.'' Here we again read that climatic variation is for terrestrial life its most fundamental evolutionary factor. And this was especially true for the Pleistocene, when the land biotas ''have come and gone at the command of climatic change. Those animals which were trapped on the northern sides of mountain ranges or water barriers were remorselessly exterminated by the waves of advancing cold; those which could escape to the south returned with milder climates, but changed in their assemblage.'' Barrell held that man was brought to his present high physical and mental state not as the ''mere product of time and life,'' but that he is ''peculiarly a child of the earth and is born of her

vicissitudes." "The progress of life on the earth has been highly favored, consequently, by the rhythmic pulses of diastrophic and climatic changes which have remorselessly urged forward the troop of living creatures. The progress of organic evolution has depended on a series of fortunate physical events, conditioned in the internal nature of sun and earth, rather than the by-product of mere life activities as expressed in orthogenesis through long periods of time. Organic evolution is in no sense an inevitable consequence of life, and the compulsion of climatic change has been more than once a fundamental factor in the age-long ascent from protozoan to man."

## Bibliography.

### *Published Works.*


1899—Rocky Mountain mine surveying: Some convenient methods which are especially suited to the conditions there met. Mines and Minerals, vol. 19, pp. 241-244.

Corrections for errors in mine surveying. Ibid., vol. 19, pp. 433-437.

Stope books. Methods for keeping precise records of stopes. Ibid., vol. 20, pp. 97-100.

1900—The real error of a survey. Some notes on the accuracy of surveys in inclined seams and an analysis of the sources of error. Ibid., vol. 20, pp. 299-301.

Surveys in inclined shafts. Theoretical and practical considerations governing the choice of instruments. Ibid., vol. 20, pp. 420-421.

Review of "A memoir on the Paleozoic reticulate sponges constituting the family Dictyospongidæ," by James Hall and John M. Clarke. This Journal (4), vol. 9, pp. 224-228.

1902—Microscopical petrography of the Elkhorn mining district, Jefferson County, Montana. U. S. Geol. Survey, 22d Ann. Rept., pt. 2, pp. 511-549.

The physical effects of contact metamorphism. This Journal (4), vol. 13, pp. 279-296.

1904—Review of "The evolution of earth structure," by T. M. Reade. Ibid., vol. 17, pp. 250-251.

Recent studies of the moon's features. Ibid., vol. 18, pp. 314-318.

Review of "Treatise on metamorphism," by C. R. Van Hise. Ibid., vol. 19, pp. 251-256.

1906—Relative geological importance of continental, littoral, and marine sedimentation. Jour. Geology, vol. 14, pp. 316-356, 430-457, 524-568.

Review of "A contribution to the oceanography of the Pacific," by J. M. Flint. This Journal (4), vol. 21, pp. 333-335.

Review of "The geodetic evidence of isostasy," by J. F. Hayford. Ibid., vol. 22, pp. 185-186.

1907—Geology of the Marysville mining district, Montana: a study of igneous intrusion and contact metamorphism. U. S. Geol. Survey, Prof. Paper 57, pp. 178, 16 pls.

Review of "Lunar and Hawaiian physical features compared," by W. H. Pickering. This Journal (4), vol. 23, pp. 228-229.

Review of "Manual of the geology of Connecticut," by W. N. Rice and H. E. Gregory. Ibid., vol. 23, pp. 385-392.
Review of "The place of origin of the moon—the volcanic problem," by W. H. Pickering. Jour. Geology, vol. 15, pp. 503-506.
Origin and significance of the Mauch Chunk shale. Bull. Geol. Soc. America, vol. 18, pp. 449-476. Abstract in Science, new ser., vol. 25, p. 766.

1908—Relations between climate and terrestrial deposits:
Pt. I. Relations of sediments to regions of erosion. Jour. Geology, vol. 16, pp. 159-190.
Pt. II. Relation of sediments to regions of deposition. Ibid., pp. 255-295.
Pt. III. Relations of climate to stream transportation. Ibid., pp. 363-384.
Abstracts in Science, new ser., vol. 25, 1907, p. 766; and Bull. Geol. Soc. America, vol. 18, 1906, pp. 616-621.
Schaeberle and geological climates. Science, new ser., vol. 28, pp. 371-373.

1909—Review of "The tidal and other problems—Contributions to cosmogony and other fundamental problems of geology," by T. C. Chamberlin and others. This Journal (4), vol. 28, pp. 188-196.
Review of "Research in China," by Bailey Willis, Eliot Blackwelder, and R. H. Sargent. Science, new ser., vol. 29, pp. 257-260.
Some distinctions between marine and terrestrial conglomerates. (Abstract.) Science, new ser., vol. 29, p. 624; also Bull. Geol. Soc. America, vol. 20, 1910, p. 620.
Fair play and toleration in criticism. Science, new ser., vol. 30, pp. 21-23.

1910—Influence of earth shrinkage on the distribution of continental seas. In "Paleogeography of North America," by Charles Schuchert. Bull. Geol. Soc. America, vol. 20, pp. 506-508.
Discussion of paper by Ellsworth Huntington on "Post Tertiary history of the lakes of Asia Minor and Syria." Ibid., vol. 21, p. 756.
Discussion of paper by W. H. Sherzer on "Criteria for the recognition of sand grains." Ibid., vol. 21, pp. 775-776.
Review of "Radio-activity and geology," by J. Joly. This Journal, (4), vol. 29, pp. 83-85.
Review of "The figure of the earth and isostasy from measurements in the United States," by J. F. Hayford. Ibid. (4), vol. 29, p. 193.
Review of "Paleogeography of North America," by Charles Schuchert. Ibid., vol. 29, pp. 552-557.
Review of "The mechanics of the earthquake" (California, 1906), by H. F. Reid. Ibid., vol. 30, pp. 287-290.
A vision of Yale in 6010. Yale Alumni Weekly, March 11, pp. 611-612.
The lithology of Connecticut. Pt. I, An outline of lithology. Connecticut State Geol. Nat. Hist. Survey, Bull. 13, pp. 17-131, 6 tables.

1912—Criteria for the recognition of ancient delta deposits. Bull. Geol. Soc. America, vol. 23, pp. 377-446.
Review of "On the origin of the Himalaya Mountains, a consideration of the geodetic evidence," by S. G. Burrard. This Journal (4), vol. 34, p. 489.

1913—Piedmont terraces of the northern Appalachians and their mode of origin. (Abstract.) Bull. Geol. Soc. America, vol. 24, pp. 688-690. Also in Preliminary Program, New Haven meeting, Geol. Soc. America, 1912, pp. 18-20.
Post-Jurassic history of the northern Appalachians. (Abstract.) Bull. Geol. Soc. America, vol. 24, pp. 690-691, 694-696. Also in

Preliminary Program, New Haven meeting, Geol. Soc. America, 1912, pp. 20-21.

Discussion of paper by A. W. Grabau on "A classification of marine deposits." Bull. Geol. Soc. America, vol. **24**, pp. 713-714.

Field and office methods in the preparation of geologic reports; measurements by compass, pace, and aneroid. Econ. Geology, vol. **8**, pp. 691-700.

A Yale honors school. Yale Daily News, Dec. 16, pp. 1, 6.

1913–1914—The Upper Devonian delta of the Appalachian geosyncline:

Pt. I. The delta and its relations to the interior sea. This Journal (4), vol. **36**, pp. 429-472.

Pt. II. Factors controlling the present limits of the strata. Ibid., vol. **37**, pp. 87-109.

Pt. III. The relations of the delta to Appalachia. Ibid., pp. 225-253.

1914—(With Charles Schuchert.) A revised geologic time-table for North America. Ibid., vol **38**, pp. 1, 17-23, 26, 27.

Review of "Principles of stratigraphy," by A. W. Grabau. Science, new ser., vol. **40**, pp. 135-139.

The status of hypotheses of polar wanderings. Ibid., vol. **40**, pp. 333-340.

The seismograph at the Peabody Museum. Yale Daily News, Dec. 8, p. 3.

1914–1915—The strength of the earth's crust:

Pt. I. Geologic tests of the limits of strength. Jour. Geology, vol. **22**, pp. 28-48.

Pt. II. Regional distribution of isostatic compensation. Ibid., pp. 145-165.

Pt. III. Influence of variable rate of isostatic compensation. Ibid., pp. 209-236.

Pt. IV. Heterogeneity and rigidity of the crust as measured by departures from isostasy. Ibid., pp. 289-314.

Pt. V. The depth of masses producing gravity anomalies and deflection residuals. Ibid., pp. 441-468, 537-555.

Pt. VI. Relations of isostatic movements to a sphere of weakness—the asthenosphere. Ibid., pp. 655-683.

Pt. VII. Variation of strength with depth, as shown by the nature of departures from isostasy. Ibid., pp. 729-741, vol. **23**, pp. 27-44.

Pt. VIII. Physical conditions controlling the nature of the lithosphere and asthenosphere. Ibid., pp. 425-443, 499-515.

1915—Origin of the solar system under the planetesimal hypothesis. In "Text-book of geology," by L. V. Pirsson and Charles Schuchert, pp. 513-526.

Review of "The climatic factor as illustrated in arid America," by Ellsworth Huntington. Jour. Geology, vol. **23**, pp. 95-96; also in this Journal (4), vol. **38**, 1914, pp. 563-567.

Intercollegiate geological excursion of New England. (Unsigned.) Bull. Amer. Geog. Soc., vol. **47**, pp. 872-873.

Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene. This Journal (4), vol. **40**, pp. 1-22. In modified form in Jour. Washington Acad. Sci., vol. **5**, pp. 413-420.

Central Connecticut in the geologic past. Connecticut State Geol. Nat. Hist. Survey, Bull. **23**, pp. 6-44. Originally published in much shorter form under the same title in Wyoming Hist. Geol. Soc., Proc. and Coll., vol. **12**, 1912, pp. 25-54.

1916—Review of "Origin of the earth," by T. C. Chamberlin. Science, new ser., vol. **44**, pp. 239-244.

The fourteenth New England Intercollegiate Geological Excursion. Ibid., vol. **44**, pp. 701-703.

1916—Geology an important part of a comprehensive education. Yale Daily News, April 12, pp. 1, 5.
Discussion of paper by Sidney Paige on ''Mechanics of intrusion of the Black Hills Precambrian granite.'' Bull. Geol. Soc. America, vol. 27, pp. 104-105.
Discussion of paper by R. W. Sayles on ''Banded glacial slates of Permocarboniferous age, showing possible seasonal variations in deposition.'' Ibid., vol. 27, pp. 112-113.
Dominantly fluviatile origin under seasonal rainfall of the Old Red Sandstone. Ibid., vol. 27, pp. 345-386. In shorter form in Proc. Nat. Acad. Sci., vol. 2, pp. 496-499.
The influence of Silurian-Devonian climates on the rise of air-breathing vertebrates. Bull. Geol. Soc. America, vol. 27, pp. 387-436. In shorter form in Proc. Nat. Acad. Sci., vol. 2, pp. 499-504.
1917—Rhythms and the measurements of geologic time. Bull. Geol. Soc. America, vol. 28, pp. 745-904.
Probable relations of climatic change to the origin of the Tertiary ape-man. Sci. Monthly, vol. 4, pp. 16-26.
1918—A century of geology, 1818-1918: The growth of knowledge of earth structure. This Journal (4), vol. 46, pp. 133-170. Also in ''A century of science in America,'' pp. 153-192, Yale Univ. Press, 1918.
The origin of the earth. In ''The evolution of the earth and its inhabitants,'' pp. 1-44, Yale Univ. Press.
1919—Sources and tendencies in American geology. Sci. Monthly, vol. 8, pp. 193-206.
The place of modern languages in research, particularly in geological research. Ibid., pp. 481-495.
Review of ''Fossil plants from Bolivia and their bearing upon the age of uplift of the Eastern Andes,'' by Edward W. Berry. The Geogr. Review, May, 1919, pp. 353-354.
The nature and bearings of isostasy. This Journal (4), vol. 48, pp. 281-290.
Outline of the theory of isostasy. Ibid., pp. 291-338.

*Unpublished manuscripts.*

1897—The geological history of the Archean highlands of New Jersey, including their extension in New York and Pennsylvania (not to be published).
1908—Report upon the fire clays in the vicinity of the Illinois River south of Peoria, Illinois (not to be published).
1910—Marine and terrestrial conglomerates.
1914—Relations of subjacent igneous invasions to regional metamorphism.
1915—Genealogy of the Barrell family (not to be published).
Relations of Pleistocene warping to strength of crust (not to be published).
1916—Geological relations of earth condensation and resulting acceleration in rotation.
1917—The genesis of the earth.
Undated—The strength of the earth's crust. Pt. IX. The problems involved in the temperature gradient conforming to the curve of crustal strength (not to be published).
The Lower Cambrian of the southern Appalachians.
Piedmont terraces.
Description of the Housatonic quadrangle.
Index to structure section, Sheffield-Sandisfield folio.

# Art. XX.—*The Nature and Bearings of Isostasy;** by Joseph Barrell.

The greater part of thinking in the field of dynamical and structural geology is based upon the evidences revealed in the exposures of the rock outcrops or their syntheses as expressed in the geologic map. Yet these structures are of a small order of magnitude as compared to those larger structures which underlie the grander features of our planet. Important though these

* A non-technical summary of six lectures delivered before the Geological Department of Columbia University, March 28-April 13, 1916. This summary was probably written shortly after the lectures were given, but has not as yet been published. The lectures rest in large part upon a series of papers published by Professor Barrell in the Journal of Geology in 1914 and 1915 under the general title of "The Strength of the Earth's Crust."

The synopsis of these six lectures "On the Nature and Bearings of Isostasy," as published by Columbia University is as follows:

March 28.—*The larger relief of the earth.* Continental platforms and ocean basins: plateaus and deeps: folded and overthrust mountain ranges. Contrast with Moon and Mars. Views of Dana, Fisher, Suess, and Chamberlin on the origin and maintenance of the larger features of the earth. Fundamental nature of the problems.

March 30.—*The geodetic evidence of isostasy.* Contributions of Pratt, Airy, Dutton, Putnam and Gilbert, Hayford and Bowie. Astronomic and geodetic coördinates and resulting deflection residuals. Gravity measurements and gravity anomalies. Differences of these according to hypotheses used. Sum of least squares of residuals as a test of hypotheses. Results of the application of the theory of isostasy to geodetic measurements.

April 4.—*The regional distribution and incompleteness of isostasy.* Evidence from erosion and deposition; from continental glaciers; from grouping of deflection residuals and gravity anomalies. Magnitude of the loads due to variations in crustal density not in accord with topography. Power of the geodetic method for future geologic investigation.

April 6.—*Evidence of isostasy on distribution of strength.* Stresses existing as a consequence of isostasy and mode of readjustment for maintenance of isostasy. Incompetence of isostatic movements to produce folding or overthrusting. Stresses produced by harmonic excesses or defects of mass. Geological processes which lead to an adjustment of stresses to fit the distribution of strength. The curve of strength for lithosphere and asthenosphere.

April 11.—*Physical conditions controlling the nature of lithosphere and asthenosphere.* Distinctions between rigidity and strength. Physical conditions in a shell of weakness,—the asthenosphere. Adjustment to evidence from tides and earthquakes. Relations to igneous activity. Relations to radio-activity and length of geologic time.

April 13.—*Bearings of isostasy on origin of continents and mountains.* Elimination of the tetrahedral hypothesis. Continents not built up by weathering during earth growth. Difficulties confronting Fisher's hypothesis of the origin of ocean basins through the separation of the moon. Difficulties of the hypothesis of continental fragmentation. No final solution yet given. Crustal shortening the result of centrospheric shrinkage. Relations of epeirogenic and orogenic movements.

details are from the standpoint of the working geologist, their study is comparable to the close study of the technique of a painting whose motive and artistic effects are visible only from a distance. It is the larger conception which determines the expression of the details.

To obtain a comprehensive knowledge of the earth as a basis for research, to perceive the larger principles whose workings are expressed in the smaller features, we must seek to understand the dynamical conditions within the earth as comprehensively as we have come to understand the gradational forces which work upon its surface. The earth in its major divisions of continental platforms and ocean basins, in its subdivisions of plateaus, deeps, and the folded mountain arcs, possesses an individuality which contrasts it to those two celestial bodies, the moon and Mars, which are free from concealing envelopes of cloud and near enough to show us through the telescope the character of their surface features. It is the relation of variable density in the crust to this distinctive relief of the earth's surface which is the subject matter of isostasy.

It is a field which, as may be seen by a preliminary survey, is related to many of the larger and still unsettled problems of geology. Going back in thought to the origin of the continents, we may note the great contrasts in the hypotheses which have been put forth. Dana regarded the major relief of continent and ocean floor as obtained in the original freezing of a crust and consequent upon the faster cooling and shrinkage of certain portions. Fisher advanced the supposition that in primordial times the earth rotated so fast that a part of the siliceous crust, that of the Pacific hemisphere, broke away to form the moon. Australia and the Americas cracked free and floating away from the remaining portion of the crust drifted toward the great Pacific depression. Suess has built up the hypothesis of continental fragmentation, by which process he conceived the margins of the continents to have faulted down into periodically widening ocean basins. The process, according to him, has continued through geological time and he looked forward to a planet in which the continental relief might disappear, the lands giving place to oceans and terminating the career, save for a few marine adaptations, of all those animals which breathe with lungs. Chamberlin, on the contrary, has argued that the continental plat-

forms were built up during earth growth, their nature rooted deep in the planet, and their outlines, excluding the shifting shallow seas, essentially constant through all the ages.

Some of the most significant tests of these hypotheses are derived from the quantitative measurement of the relations of the density of the crust to the relief of its surface.

From 1849 to 1855 it was shown by Petit, Pratt, and Airy that certain mountain regions were matched in their elevations by a deficiency in density. They floated, as it were, in the solid earth for the same reason that an iceberg stands above the ocean level because of its lesser density. According as this relation is more or less exactly attained, the strains imposed by the weight of continents and mountains upon the interior of the earth are largely eliminated. The geologic bearings of this theory of the relations of relief to density were perceived by Dutton, and in 1889 he coined for it the name of isostasy. A few years later Gilbert and Putnam made the first quantitative measurement of isostatic relations in North America. In the past ten years, however, the subject has been brought to a quantitative basis by means of the geodetic data contributed by Hayford and Bowie. Hayford reached the conclusion from his study of deflections of the vertical that the average departure of the surface from that level which would give perfect isostasy was not more than 250 feet and that the horizontal limits of such a departure were between one square mile and one square degree. The work of the writer has been based in considerable part upon a reinterpretation of the data given by Hayford and Bowie, but has reached the conclusion that the isostatic balance for limited areas is much less complete than Hayford believed. The vertical magnitude of the departure from isostasy permitted by the strength of the earth varies inversely with the areal extent. An area two hundred miles in diameter may stand probably with an average elevation as much as 1,000 feet above or below that level giving perfect isostasy, and loads several times as great as this appear to be borne in places.

Following this preliminary survey, a statement will be made of the nature of the geodetic evidence upon which the quantitative measurement of isostasy rests.

The astronomic determinations of latitude and longi-

tude depend upon very precise measurements of the point in which the projected vertical at any station pierces the celestial sphere, measured by reference to the stars. The geodetic determinations, on the other hand, are made by very precise triangulations from a network of other stations, knowing the size and shape of the geoid. The geodetic and astronomic coördinates of the same station will differ because of the deflections of the vertical produced by the gravitative effect of the topographic relief and the heterogeneities in density. Let it be assumed for purposes of calculation that every detail in topography is balanced or "compensated" by a corresponding variation in density. Suppose these variations are uniformly distributed down to a certain datum plane, at which level they abruptly cease. There is postulated then a condition of perfect isostasy depending upon a uniform density compensation which extends to a certain depth of complete compensation. This is the form of hypothesis which Hayford adopted, necessarily artificial, but one which lends itself readily to mathematical calculation. On this basis let the gravitative influence be calculated of the surrounding topography and its assumed compensation acting upon the vertical at each station. This gives a correction to the deflections of the vertical which modifies the geodetic coördinates as obtained without the aid of the theory of isostasy. Note the remaining unexplained divergence between the astronomic and these modified geodetic calculations of the directions of the vertical or plumb line. They are found to possess an average value of about three seconds of arc. These differences in the meridian and also in the prime vertical for each station are the *deflection residuals.* They rest upon the imperfections of the measurements plus the imperfections of that hypothesis of isostasy which was adopted. The errors of measurement are small in comparison, and in a large number of observations would tend to cancel out. A perfect theory of isostasy (not a theory of perfect isostasy) would reduce to zero that part of the residuals due to the hypothesis. Hayford's hypothesis of uniform compensation to a depth of 122 kilometers reduced the sum of the squares of the residuals to a quantity less than one-tenth of the sum of the squares which is obtained under the hypothesis that there is no isostatic compensation, or that the compensation was uniformly distributed

through a great part of the earth's body. It is to be concluded, therefore, that the larger relief of the earth is on the average nearly compensated by density variations which occur mostly within 122 kilometers of the surface.

Another and independent method of investigation is based upon the direct measurements of the intensity of gravity at many stations by means of the pendulum, and comparing the results with the gravity at each station as calculated for latitude and elevation and modified by the influence of the topography of the whole earth and its assumed isostatic compensation. The difference between the observed and calculated values of gravity at each station, adjusted to the hypothesis of isostasy, is known as the *gravity anomaly.* The results of such an investigation confirm the evidence of the degree of isostasy and depth of compensation as obtained from astronomic and geodetic measurements.

Having reached this conclusion, the study of the nature of the deflection residuals and gravity anomalies becomes of the first importance, for they measure the differences at each locality between the actual conditions in the earth's crust and the simple ideal of Hayford's hypothesis. It is this subject especially which the writer has studied.

The results indicate that individual mountain ranges like the Front Range of the Rocky Mountains may be sustained by the rigidity of the crust, this being found to be true at Pike's Peak; but broader areas, such as the Great Basin, are largely supported by corresponding variations in crustal density. Unit areas two hundred miles across may lie on the average, as previously stated, more than one thousand feet above or below the level giving isostatic equilibrium, but an area as broad as a continent probably lies as a whole at an elevation considerably within a thousand feet of the isostatic mean. It appears that the major relief of the earth, that between continent and ocean basin, is as much as nine-tenths compensated, perhaps somewhat more, since the regional departures from isostasy tend to mask the broader approach toward isostasy. The present epoch, however, may, as Willis has observed, be an epoch which, because of recent diastrophic adjustment, shows an unusual degree of isostatic equilibrium.

In regard to the differences in the vertical distribution

of the variations of density between the simple ideal of Hayford and the facts of nature, it would appear that compensation is not uniform with depth, but occurs mostly within the outer hundredth of the earth's radius, forty miles, tapering out to a depth several times as great and reaching in some regions perhaps to 200 miles.

Lines of evidence other than those derived from geodesy have a bearing on the degree of isostatic warping in response to load. The warpings of the crust beneath the burden of the Pleistocene ice sheets offer interesting studies in this connection. The warpings showed a lag and followed broader lines than the contours of the individual lobes of ice. The burdens of ice sustained by the crust and the regional yielding under greater loads correspond in order of magnitude with the capacity to support the loads of sediment deposited by the Nile and the Niger, as shown by the constructional form of these typical deltas, but the yielding to larger loads imposed by mountain systems. The capacity of a land surface to remain stationary during a cycle of erosion is also to be noted. These various geologic tests of the incompleteness and regional nature of isostasy are in accord with the geodetic evidence as here interpreted.

Another type of problem consists in the determination, by means of the departures from isostasy, of the location and magnitude of great bodies of rock of abnormally high or low density. Beneath the plains in the center of the continent these internal loads, both positive and negative, are found to impose burdens on the crust as great as those given by uncompensated mountain masses. For illustration, a great body of heavy rock, presumably gabbro, equivalent to a disc approximating 120 miles in diameter and a thickness of perhaps three miles, is thus found to underlie an area in central Texas. In the neighborhood of Seattle, on the other hand, a remarkable deficiency of density suggests the possibility of the existence there of a massive abyssal body of magma, a batholith still unsolidified.

We come next to some of the larger bearings of isostasy. Its existence and degree of perfection having been determined, it may be used in turn to throw light on many problems of the earth's interior. Chief among these perhaps is the evidence of isostasy on the distribution of strength.

The experiments of Adams have shown conclusively that for the conditions of temperature and pressure which exist in the outer crust the strength greatly increases with depth up to at least 15 or 20 kilometers. The degree of maintenance of isostasy through geological time in spite of opposing agencies shows, on the other hand, that a deeper shell in the earth is very much weaker than the surface rocks. Under the supposition that various geological agencies have loaded the crust to near the limit of its strength and that the condition of isostasy is due to failure beyond that limit, the strength may be determined for various depths and an approximate curve of strength may be drawn. The shell of weakness revealed by isostasy as existing below the shell of isostatic compensation is thought to have very fundamental relations to the architecture of the earth, the mode of expression of its internal forces, and to the origin of magmas. As weakness under permanent shearing stress is its conspicuous feature, it is named the asthenosphere, the far stronger crust above being the lithosphere. Without such an asthenosphere it is thought there could be no notable degree of isostasy.

How do these conclusions regarding the physical nature of the asthenosphere correspond with the evidences of high rigidity derived from the small degree of yielding to tides and earthquakes? At first sight there seems to be a sharp disagreement between two well-established lines of evidence. This paradox appears to be due, however, to a confusion of the conceptions of rigidity and strength. Rigidity is increased with pressure and increase in rigidity corresponds to a rise in the moduli of elasticity. Strength, on the other hand, is measured by the elastic limit, beyond which solid flowage takes place. Under permanent load and temperatures near fusion the solid yields to moderate permanent stresses by recrystallization without the moduli of elasticity being changed. Under these conditions high rigidity is compatible with low elastic limit.

In conclusion there will be discussed briefly, in answer to the questions raised in the introduction, the bearings of isostasy on the hypotheses dealing with the origin of ocean basins and continental platforms. Two of these hypotheses are at present more particularly before the public; they have been formulated by two of the leaders

in geologic thought, and in this summary attention will be given to these views alone.

Suess developed, without regard to the theory of isostasy, his theory of continental fragmentation as a process continuing through geological time. In fact he formulated his views before the very word isostasy had been coined and long before the quantitative data proving it were available. These data indicate that a continental platform cannot break down *broadly* into an ocean basin *unless* there has been a previous or accompanying increase in density in the lithosphere. Such an increase in density might be made locally by the rise of great masses of basic or ultra-basic magmas, but there is no independent geologic evidence that this has occurred on the scale demanded by the theory of Suess, nor that it could be effective on such a scale. The possibility of broad density changes cannot, however, be excluded. Therefore if the geological evidence of continental fragmentation should become regarded as compulsory, the evidence that isostatic compensation is mostly restricted to the outer fiftieth of the earth's radius and that large sections of the crust lie at a level giving approximate isostasy would go to show that density changes otherwise unsuspected have progressively gone forward in the lithosphere through geological time. Thus the two conditions of fragmentation and isostatic compensation may conceivably be reconciled by the existence of a third and otherwise unsuspected condition of changes of density in the lithosphere.

Let us turn next to Chamberlin's views on the origin of continents and ocean basins. He has advanced the hypothesis that the continents have been built up from lighter material segregated by surface processes during the growth of the earth by planetesimal infall. In accordance with this mode of origin he holds to a view that the earth is composed of a limited number of large and strong conical sectors, the bases of the cones being the ocean basins, the apices lying deep in the central core of the earth. Diastrophism, under the terms of this hypothesis, occurs by means of movements of adjustment of these cones with respect to each other and a mashing of the weaker continental sectors which constitute yield tracts between them. The continental sectors are assumed to be in approximate hydrostatic equilib-

rium with the conical oceanic sectors, thus giving a form of isostasy in which the compensation extends downward more than a thousand miles. To balance the elevation of the continents above the ocean basins Chamberlin states that the oceanic sectors would have to possess only about one-fifth of one per cent. greater density.[1] Chamberlin recognizes the essential difference between this kind of isostasy and that which rests upon a compensation restricted to an outer shell of the earth, mostly within an outer fiftieth of the radius. The limitations of differences of density in depth are not regarded by him as having any trustworthy basis, and he states that this view is supported by competent mathematical investigation, the results of which will appear in time.[2]

A final settlement of this question must wait until such full investigations as Chamberlin promises have been published and have been tried out against the opposing views which have been here adopted. We have found occasion to differ from Hayford in many particulars, but have modified his hypothesis in detail and in degree rather than in its central idea. The least-square solutions seem to point mathematically and conclusively to a concentration of the isostatic compensation in an outer shell, though Hayford himself notes that the form of hypothesis which restricts it to a *uniform* distribution to a *uniform* depth of 122 kilometers has no certainty over some other forms of distribution of compensation. But to satisfy the least-square solutions all hypotheses must restrict the compensation to an outer zone. Various other and independent lines of investigation, such as the yielding under the Pleistocene ice loads and the determination of the curve of strength, support the geodetic evidence that isostatic compensation is largely limited to the outer fiftieth of the earth's radius. Therefore, until Chamberlin has shown the error in these demonstrations and has published in detail the mathematical basis which supports his own view, we are justified in holding to the probability of the hypothesis here set forth,—that an outer shell of strength and heterogeneous density rests upon a yielding shell of weakness. There has not been published as yet any contrary demon-

[1] Chamberlin and Salisbury, Geology, Vol. II, pp, 110, 111, 123, 1906. Chamberlin, The Origin of the Earth, pp. 159-225, 1916.

[2] T. C. Chamberlin, Isostasy in the Light of the Planetesimal Theory, this Journal, vol. 42, p. 371, 1916.

stration that diastrophism takes place by adjustment between deep conical sectors, or that the continental platforms originated in the manner advocated by Chamberlin. This statement, however, should not be taken as a criticism of the planetesimal hypothesis. It is a difference merely in regard to one important line of deduction derived from that hypothesis. The data of isostasy must ultimately constitute the test of that deduction. So far as now understood the isostatic data are against it.

It has been the purpose of these lectures to show the methods of investigation which have given us a knowledge of isostasy and of the relations which the theory of isostasy bears to a variety of geologic problems, both in regard to the structure and strength of the crust as well as to the more ulterior problems of origin.

# Art. XXI.—*The Status of the Theory of Isostasy;* by JOSEPH BARRELL.*

Contents.



## Outline of the Theory of Isostasy.

Isostasy embraces the theory of relationships between the relative surface relief of segments of the earth's crust and the densities of those segments. It is a subject closely related to the geological history of continents and ocean basins, and almost as closely to the nature of igneous rocks and the modes of deformation during periods of terrestrial revolution. Although one of the larger fields of geological theory, it is in a concrete form still relatively new and receives either no notice or but bare mention in the geologic texts published during the past ten to twenty years. The valuable literature on the subject is largely technical and removed from the field of the geologist. There is still need, consequently, for a general statement of isostasy before passing into consideration of details. Especially is there need of showing the relationships of isostasy to other fields of geologic theory, in order that the importance and bearings of the subject may become more widely appreciated.

This article is written in enough detail to be clear to readers who have not closely followed the history of the subject. In the introductory sections the theory of isos-

* This paper was written for the Journal and was in the hands of the typist at the time of Professor Barrell's death, May 4, 1919. It was his custom to give his papers a final critical reading when in typewritten form. Usually he made only verbal changes but at times entire passages were rewritten. As he has published extensively upon isostasy before, however, and as his reasoning upon this subject had presumably attained to maturity, it is not likely that he would have made extensive changes in this paper. It therefore is thought probable that it appears as he would have presented it. Here and there a few words have been added and minor changes in punctuation made. C. S.

tasy is assumed to be true on the basis of work previously published by many investigators during the past half century. The later sections will discuss in detail certain recent adverse criticisms which may have seemed to some readers to undermine the solid basis on which isostasy was thought to rest. Those criticisms, in so far as they are against isostasy rather than against some subordinate or unessential hypothesis, are found here to be invalid. The conclusion therefore is reaffirmed that for regions sufficiently broad, and to variable degrees of perfection, the evidence is now convincing that the high or continental areas of the surface are underlain by lighter matter than are the low, or oceanic, areas. This relation is maintained closely enough over varied conditions to lead to the further conclusion that the relationship is one of cause and effect. Over broad high areas the mean elevations are high *because* the crustal densities are there low, and *vice versa,* the mean surface of low areas is low *because* the densities there are high. This is quite closely true for the relations of continents and ocean basins but to lesser and lesser degrees for the smaller and smaller subdivisions of these major segments of the crust. The subject remains problematic only in regard to closeness of adjustment and limits of area involved. The larger features of the earth's surface are, therefore, sustained in solid flotation, and at some depth the strains due to the unequal elevations largely disappear, the elevations being compensated by variations of density within the crust. In consequence the subcrustal shell is subjected to but little else than hydrostatic pressure. This conclusion regarding equilibrium of pressure in a subcrustal shell is embodied in the name *isostasy,* proposed by Dutton in 1889, meaning equal pressures. Above this shell, whose upper part though gradational is not more than 80 or 100 miles deep, every radial column of adequate area, say 100,000 square miles, contains very nearly the same mass as every other column of equal area, although the mean surfaces of ocean and continental columns may be several miles different in elevation.

Thus far we may speak of the *theory* of isostasy and regard its existence as demonstrated in the same way that astronomers have demonstrated the existence of small cyclic variations of latitude and the motion of the

sun in space, namely, by the bringing into harmony, except for minor irregular discrepancies, of calculation and observation on large assemblages of precisely measured data. Beyond this broader demonstration of the existence of isostasy lies, however, the field of competing *hypotheses*. Such questions arise as: How closely related in horizontal area are the elevations and corresponding defects in density? How closely balanced are the elevations and densities? How near the surface are the corresponding variations and in what manner do they disappear with depth? What are the causes of variations of density and to what degree have they remained constant for each area through geologic time? To what degree are these questions determinate and to what degree indeterminate?

The quantitative data are mostly astronomic and geodetic, depending upon very precise measurements of the direction of the vertical and the intensity of gravity; the interpretation, however, is mostly geologic, having to harmonize the geodetic indications with other aspects of earth structure and history. Geodesists have been hampered in interpretation from the fact that they were not geologists; geologists have been hampered in weighing the force of the geodetic evidence because of lack of familiarity with the mathematics of the geodesist.

In order to subject a large mass of complex data to mathematical analysis, simple mathematical hypotheses must be introduced and tested to see if they reduce the data to some degree of order. Thus, in the determination of star drift and the sun's way through space relative to the stars, the average motions of groups of stars are determined. A certain proportion of the drift, in so far as it is common to all the stars, is regarded as due to the sun's motion with respect to the stars. The outstanding differences represent the errors of observation combined with the random motion of the individual stars and groups of stars with respect to each other.

In the analysis of the geodetic data bearing on isostasy, a simple mathematical picture is consequently introduced, but no one should imagine that nature is really so simple as the mathematical picture of hypothesis. The geodesist, while freely admitting this distinction, tends to minimize it; the geologist, familiar with the complexities of earth structure and seeing that topographic relief

of the land is more dependent upon erosion than upon hidden density, tends to magnify the differences between nature and the mathematical picture.

The subject of isostasy has grown through the past half century, but has been brought into the field of exact analysis in the past decade by the comprehensive and very valuable geodetic researches of Hayford and Bowie. The writer, in common with some other geologists, was unable, however, to accept the geologic interpretation which Hayford gave to his work with the implication that whether geologists liked it or not they must accept it, and some years ago, in order to test the validity of the geodetic evidence and its geologic implications, made an extensive investigation of the geodetic data.[1] Since that time a number of articles of various values, some supporting the theory of isostasy, some adverse to it, have appeared. As giving source material especially, should be mentioned Bowie's most important monograph,[2] which has greatly extended the data previously available and has treated them from some new standpoints. The time seems appropriate therefore for a further review and analysis of this subject.

As the following analysis must deal largely with the simple mathematical pictures, the impression might be given that a writer mistakes them for the realities of nature. It is desirable, therefore, before taking up the details of the subject, to state briefly the general conclusions entertained regarding the limits of isostasy. The writer believes the evidence demonstrates beyond controversy that the larger relief of the earth is in greater part balanced by corresponding variations of density within the outer fiftieth of the earth's radius, that the distortional stresses at a depth of a twentieth of the radius are only a small fraction of what they would be if the density of the outer crust were uniform. On the other hand, it is believed that the variations of density are irregular, imperfect, and mostly concentrated in the outer hundredth of the radius, with a tendency to progressively disappear with depth. The outer crust is very strong, capable of supporting individual mountains, limited mountain ranges, and erosion features of cor-

[1] Joseph Barrell, The strength of the earth's crust, Jour. Geology, vols. 22, 23, 1914, 1915.

[2] William Bowie, Investigations of gravity and isostasy, Special publication No. 40, U. S. Coast and Geodetic Survey, 1917.

responding magnitude; but it is able to flex under broader loads, so that mountain systems and broad plateaus are in greater part related to regional deficiencies in subcrustal densities. The strength of the crust is believed to vary greatly in different regions and to shade off into the weaker zone below. The span and magnitude of the possible loads vary accordingly. The broader and gentler flexures of this thick, strong crust involve but little crustal stress and therefore but limited deformation within the crust itself, but imply a broad, deep, and slow creep in the subcrustal zone. This creep, provided the yielding zone is thick, involves but small distortion of a unit mass and is thought to be coexistent with the maintenance of a solid and rigid state. The probable mode of yielding is by recrystallization under strain, analogous to the mechanics of the flow of glacial ice.

This combination of a strong, thick crust resting on a weak but solid subcrustal shell is very different from the picture set up by the extreme isostasists, on the one hand, of a weak and failing earth, yielding isostatically in its outer part to each minor change of load; and is considerably different, on the other hand, from those hypotheses of the earth's internal nature and mode of deformation which have been elaborated without recognition of isostasy. These contrasts of interpretation point to the need for further discussion and investigation, with the object of bringing antagonistic points of view into harmony.

## Definitions Involved in Isostasy.

In order to discuss in detail the problems of isostasy, the meaning of the phraseology must be held clearly in mind. For this reason figure 1 is given.

Let A be a section of the continental crust, and B a section of the crust beneath the oceans. They are both portions of the lithosphere or rock shell whose outer part is open to geologic study. The weight of the two sections of the crust is equal for equal areas. The mean density of A is therefore less than the density of a column whose mean surface is at sea level. The difference is known as the *defect of density.* The density of B is greater than the sea level column. The difference is a negative defect of density. The mass above sea level

is balanced by a deficiency of mass below sea level. The deficiency of mass is known as the *isostatic compensation.* For the oceanic segments the isostatic compensation is an added mass. For convenience the sea level is used as the datum surface. Any other datum between the mountain summits and ocean depths could be used, since it is the difference of mass between A and B which is the quantity involved and this is independent of the datum. For convenience in computation, assumptions are introduced in regard to change of density at the datum surface which may require minor corrections according to the level of the surface.

FIG. 1.

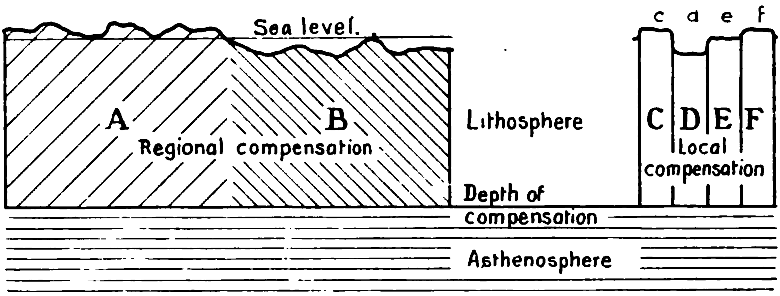


FIG. 1. Diagram to illustrate the principles of isostasy. In nature there are of course no sharp boundaries such as are drawn to make clear a diagram; the proportions also are different.

At a certain depth, known as the *depth of compensation,* the difference in density above will, for perfect isostasy, have completely neutralized the difference in surface elevations, and two sections A and B of figure 1, if of equal area, will contain the same mass.

The depth of compensation will depend upon the vertical *distribution of compensation.* If the depth of compensation is assumed equal to the radius of the earth, 6,378 kilometers, and the mean difference in elevation of A and B is 5 kilometers, the densities of A and B differ in the ratio of 5 to 6,378, or less than one part in a thousand. The body of the earth would not in that case be relieved of the loads due to the surface relief, for isostasy does not involve the absence of distortional stress in the shell above the depth of compensation. Compensation extending to the center of the earth is, therefore, equivalent to no isostasy.

If the depth of compensation is taken as 100 kilometers, the difference in densities between A and B for a differential relief of 5 kilometers would be 5 per cent. This is of the order of magnitude believed to exist.

The compensation may be conceived either: first, as existing in a certain part of the crust; second, as greatest near the surface and decreasing with depth; or, third, as uniformly distributed to the depth of compensation and there sharply terminating. Various other modes may be conceived as existing. A number of these modes of distribution satisfy the geodetic data and the most probable must be decided on geologic evidence. The depth of compensation will, however, vary according to the assumed mode of distribution.

The depth of the level of complete compensation under the *hypothesis of uniform distribution* Hayford determined at first as 114 kilometers, later as 122 kilometers, but the data do not form a sensitive index as to depth. The latest and fullest analysis by Bowie leads him to believe that future determinations will fall between 80 and 130 kilometers. Although the geodetic data do not yield a precise figure for the depth, they do show definitely that under any tenable mode of distribution practically all of the compensation lies within the outer fiftieth of the earth's radius.

In figure 1 *regional compensation* is indicated under areas A and B and *local compensation* under C, D, E, and F. The extreme of the hypothesis of local compensation is found in the assumption that each unit area, however small, is underlain by a corresponding density in its vertical column. The limit of regional compensation is to conceive a whole continent as underlain by crust of one density, an ocean basin by another density, without regarding plateaus and basins as related. The evidence indicates that neither of these extremes is near the truth. The truth, as is so commonly the case, lies between the two extremes. Regional compensation has indeterminate limits. It presumably varies in different regions, and certainly varies with the intensity and breadth of the loads to be supported. The assumption best adapted to mathematical calculation is, therefore, that of local compensation. Each unit area is given its appropriate density. Because gravity varies inversely with the square of the distance, near the geodetic station

these unit areas are small. Far away they are large. They are chosen so that each unit area will have a unit gravitative effect. But no one conceives this extreme form of local compensation to be true, but calculations of the deflection of the vertical and intensity of gravity based on such local compensation agree essentially with those based on regional compensation over areas at least as large as a square degree. For mountain regions and those near continental borders the assumption of regional compensation restricted to radial distances of 60 kilometers or less appears to give slightly better results than the assumption of regional compensation over radial distances of 167 kilometers or greater, but the discrepancies involved in taking isostasy as regional with a radius of 167 kilometers are small in comparison with other disturbing factors. At the present time the best tests as to the horizontal relationships between relief and density appear to the writer to be geologic, based on the limits of the loads which can be imposed on the crust without yielding.

Since enormous strains exist in the crust above, which when too great produce folding or faulting, it seems clear that, in so far as isostasy is true, the absence of notable strains in the zone below, notwithstanding the existence of geological agencies which tend to bring stresses upon it, implies a lack of strength in that zone. Rock flowage, like glacial flowage, must occur nearly as fast as the strains accumulate. The writer has, therefore, proposed for that zone of ready yielding the name of the *asthenosphere*, the sphere of weakness, as contrasted to the *lithosphere* above, which by comparison is a sphere of strength, and the *centrosphere* below, which is probably also more resistant.

The geodetic evidence of isostasy is founded upon a comparison of the true and calculated directions of the plumb-line at numerous stations over the United States, and in later work also upon a comparison of the true and calculated values of gravity. By introducing the hypothesis of isostatic compensation of density corresponding to the relief, the discrepancies between calculated and observed values of the direction of the vertical and the intensity of gravity were reduced on the average, as previously noted, to a fraction of what they were if no such hypothesis of density variations was introduced.

Although the average disagreement between the observed and calculated values was reduced by the introduction of the hypothesis of isostasy, the disagreements for many stations remained larger. These outstanding quantities need careful study and must be frequently referred to. For the deflections of the vertical, the outstanding discrepancies are known as the *deflection residuals.* For the intensity of gravity, the variations which remain unaccounted for by the theory of isostasy are known as the *gravity anomalies.*

Let several competing hypotheses, in regard to depth of compensation, named for convenience solutions E, H, G, etc., be tried, and the deflection residuals and gravity anomalies be determined under each hypothesis for each station. They will be different for each hypothesis. Take the squares of these individual quantities and find the sum of the squares for each hypothesis. That hypothesis which is nearest the truth will give on the average small residuals and anomalies. The relative probabilities of the hypotheses are measured by the smallness of the sum of the squares. This is a test familiar in the exact sciences, but less familiar to other branches of knowledge. Thus it is quite conclusive that under the hypothesis of *uniform vertical distribution* of compensation to the depth of compensation, that depth is much nearer 100 kilometers than 500 kilometers and certainly cannot be as great as 1,000 kilometers. This is true unless some unconscious assumption has been introduced into the calculation which modifies the residuals and anomalies in the same direction as the hypothesis to be tested. Several suggestions of such false assumptions have been put forward by critics of the geodetic evidence, but they have failed to apply or prove their own criticisms. It should be carefully noted, however, that such a test does not prove the uniform distribution of compensation to be true, but only, *if assumed,* what would be its depth. That much gained, the next step is to determine the relative probability of the mode of distribution, whether uniform or variable.

## Interpretations Favoring Local and Nearly Perfect Isostasy.

The theory of isostasy, after half a century of discussion, was placed securely upon a quantitative basis by the publication in 1909 by J. F. Hayford, inspector of

geodetic work and chief of the computing division of the U. S. Coast and Geodetic Survey, of his report on "The figure of the earth and isostasy from measurements in the United States." This memoir dealt fully with the deflections of the vertical. It was followed the next year by a supplementary report. In 1912 Hayford and Bowie published "The effect of topography and isostatic compensation upon the intensity of gravity." This work was based upon data independent of the deflections, but confirmed, in a general way, the results of the other investigation. It has been followed by two further and independent publications by Bowie. The geodetic data have been treated in a similar manner for India and the Himalayas by Crosthwait, Burrard, Hayden, and Oldham. Hecker has made many determinations of gravity at sea, but the accuracy of the shipboard determinations does not compare with the results on land. The subject of isostasy has been discussed in many articles, and contributory data have been supplied from other regions, but under the present topic it is not intended to give a complete review of the literature of the past decade, nor to touch on that which is simply of geodetic value. Certain papers which have direct geologic implications will alone be considered.

Hayford concluded that the geodetic evidence indicated the existence of a high degree of local isostatic compensation. In giving an interpretation in terms of area and elevation, he predicted that future investigations would show that the horizontal extent that a topographic feature may have without a corresponding density would be between one square mile and one square degree. Elsewhere he stated that the evidence indicated, though it did not prove, that the assumption of local compensation was nearer the truth than regional compensation to even the small distance of 18·8 kilometers from the station. The average vertical departure of the surface from the elevations giving perfect isostasy he stated in 1909 and 1910 to be less than 250 feet.

Thus Hayford was of the opinion that plateaus or basins over 25 miles in diameter and more than 250 feet above or below the mean level must be largely accounted for by corresponding variations in density extending, if uniformly distributed, to a depth of about 76 miles, the perfection of relationship increasing with the mass of

the topographic feature. As such physiographic divisions are often related to differential erosion on strata of varying hardness, the improbability of these extreme views should be evident to geologists.

Putnam and Gilbert, twenty years before, had reached the conclusion that isostatic compensation was distinctly regional, individual mountain ranges being sustained because of the rigidity of the crust. Hayford's work was so much fuller, however, that it seemed to supersede this older conclusion. It met with a varying reception from geologists which has not yet settled into a general consensus of opinion.

As illustrations of this diversity, Reid, on the other hand, accepted Hayford's work unreservedly, both the geodetic analysis and Hayford's interpretation. He then proceeded to apply it to the theory of mountain ranges, holding that all other forces and modes of explanation must be subordinated to the vertical forces maintaining an isostatic equilibrium nearly perfect.[3]

Willis, more critical, pointed out, however, that if the mountains and plains of the continents are now in isostatic equilibrium, such regions could not have been in that state before the mountains were upraised by folding. Furthermore, erosion and deposition would ultimately destroy again in considerable measure the present state of isostasy. He therefore held that if Hayford's results were correct in such detail, it meant that during a period of great crust movements, illustrated by the present geologic time, isostasy reaches a perfection which is not usual, and that therefore a high degree of isostatic adjustment does not imply such a state of weakness as would be inferred if nearly perfect isostasy were a constant condition of the crust. Willis was thus the first to test Hayford's interpretation by actually comparing it with the geologic evidence and suggesting a means of explaining the discrepancy.[4] Carrying his argument further, he has made isostatic readjustments following erosion and deposition the basis of an hypothesis of mountain folding.[5] Some serious difficulties in the way

[3] H. F. Reid, Isostasy and mountain ranges, Proc. Am. Philos. Soc., 50, 444-452, 1911.

[4] Bailey Willis, What is terra firma? Ann. Rep., Smithsonian Institution, for 1910, pp. 391-406, 1911.

[5] Bailey Willis, Research in China, Carnegie Institution of Washington, Publ. No. 54, vol. II, 1907.

of this hypothesis have been discussed by the present writer.[6]

Becker, accepting Hayford's results enthusiastically, has even gone beyond him in interpreting the supposed perfection of isostasy. Becker placed such great reliance upon Hayford's first determination of the depth of isostatic compensation, 114 kilometers, that he based a test of the age of the earth and the part of radioactivity in the crust upon this figure.[7] Bowie has since shown how indefinite is this depth of compensation. Hayford regarded the gravity anomalies as due to outstanding loads representing departures from isostasy. Gilbert showed, however, that isostasy might be perfect, and still, if the compensation occurred at various depths and especially if light and heavy masses were balanced against each other in the same vertical column, very considerable anomalies of gravity would appear. Therefore, Gilbert held that it remained to be proved to what degree the anomalies represented departures from perfect isostasy.[8] Barrell developed independently the same conclusion as Gilbert, but going farther, sought the answer as to whether the anomalies did result from mere vertical irregularity of compensation or from real departures from isostasy. By devising criteria depending on the character of the anomalies, as well as by various kinds of corroborative testimony, the conclusion was reached that the anomalies do represent in greater part such loads, positive or negative, and furthermore that the masses and resultant stresses were much larger than Hayford had supposed them to be.[9] Yet Becker in 1917 assumes without any proof or even adequate discussion that the anomalies result from mere vertical variations in the distribution of compensation, and do not measure, except to an insensible degree, real departures from isostasy.[10] Becker stands thus as the extreme exponent of perfect isostasy, going even beyond Hayford in his in-

[6] Joseph Barrell, Science, new ser., **29**, 257-260, 1909; Jour. Geology, **22**, 672-683, 1914.

[7] G. F. Becker, Age of a cooling globe in which the initial temperature increases directly as the distance from the surface, Science, new ser., **27**, 227-233, 1908; also in later publications.

[8] G. K. Gilbert, Interpretation of anomalies of gravity, U. S. Geol. Survey, Prof. Paper **85-C**, 1913.

[9] Joseph Barrell, Influence of variable rate of isostatic compensation, Jour. Geology, **22**, 209-236, 1914.

[10] G. F. Becker, Isostasy and radioactivity, Bull. Geol. Soc. Amer., **26**, 187, 1915.

terpretation and implying that the surface of the United States is everywhere almost as closely adjusted to the elevations giving equilibrium as would be the case in an arctic ice pack, where the heights of icebergs and ice floe would depend very closely on the defects of density represented by the masses of ice depressed below sea level.

How such nice adjustments between elevation and density could harmonize with knowledge regarding the strength of rocks and with the geologic evidence of considerable imperfections in isostasy, the exponents of these views never succeeded in demonstrating. Extreme interpretations frequently fall into error, and under the following topic the adjustments between various lines of evidence will be discussed.

### Interpretations Favoring Isostasy, but Regional and Imperfect in Character.

Let attention be turned to the other viewpoint, that which interprets the data as corresponding to a lesser degree of closeness in isostatic adjustment, which regards the crust as strong, the compensation as somewhat irregular, and the depth of compensation as somewhat indefinite.

Chamberlin pointed out in 1913 that the level bottoms of the old shallow seas showed the surface of the North American continent to have been controlled during previous ages by the position of the sea level over wide areas. Densities could not be supposed to be delicately adjusted to these surfaces controlled by unrelated agencies. Chamberlin accordingly maintained that the crust must be both stiff and strong. This argument is of great weight and is seen to imply that the crust is not by any means so pliable and delicately adjusted to small vertical forces as Hayford, Reid, and Becker had thought to be implied by the geodetic data.[11]

The present writer made an extensive analysis of the geodetic and geologic data in support of isostasy as a fundamental principle and yet against such close and delicate adjustment as Hayford and some others have thought to exist. This work was published as a series of eleven papers in the Journal of Geology in 1914 and

[11] T. C. Chamberlin, Shelf-seas and certain limitations of diastrophism, Jour. Geology, **21**, 523-533, 1913.

1915 under the general title, "The strength of the earth's crust." The results confirmed Gilbert's views, expressed in 1889, which he stated as follows:[12]

"It is believed that the following theorem or working hypothesis is worthy of consideration and of comparison with additional facts: mountains, mountain ranges, and valleys of magnitude equivalent to mountains, exist generally in virtue of the rigidity of the earth's crust; continents, continental plateaus, and oceanic basins exist in virtue of isostatic equilibrium in a crust heterogeneous as to density."

It was in recognition of the agreement with Gilbert's brief statement that this longer series of papers, published a quarter of a century later, was given the same title; also to offset the title of the more recent paper by Hayford entitled "The earth a failing structure."[13]

A review of the principal lines of argument given in the set of papers published in 1914 and 1915 on "The strength of the earth's crust" will be given here in order to clear the ground for such further discussion as is needed.

In Part I, on "Geologic tests of the limits of strength," it is noted that the broad and thick continental ice sheets of the Pleistocene seem to have depressed the crust, since an upwarp followed their melting, an upwarp so closely related in time and locality as to constitute strong evidence that the cause was an isostatic response to the relief of load. On the other hand, the deltas of the Nile, and especially the Niger, are constructional forms built out into the ocean basins. The maintenance of their forms shows that the crust is strong enough to bear the load, or at least that the yielding is much slower than the accumulation, very different from the geological rapidity with which the earth responded to the ablation of the greater mass of the ice sheets. Yet a conservative estimate of the mass of the Niger delta is as follows:

| | |
|---|---|
| Area within assumed limits ............. | 195,000 sq. km. (75,300 sq. mi.) |
| Radius of equivalent circle .............. | 250 km. (155 mi.) |
| Average thickness within assumed limits.. | 1.1 km. (3,600 ft.) |
| Equivalence in rock upon land .......... | 0.6 km. (1,980 ft.) |
| Maximum thickness ..................... | 3.0 km. (9,900 ft.) |
| Equivalence in rock upon land .......... | 1.65 km. (5,450 ft.) |

[12] G. K. Gilbert, The strength of the earth's crust, (Abstract) Bull. Geol. Soc. Amer., 1, 23-25, 1890.

[13] J. F. Hayford, Bull. Philos. Soc. Wash., 15, 57, 1907.

The strength of the crust is more than enough to support this load, and departures of this amount from perfect isostasy may be expected over many other parts of the globe.

Part II is on "Regional distribution of isostatic compensation," the opening portion being an explanation of the geodetic work with the evidence based on the sum of the least squares of the residuals of several solutions, showing that the hypothesis of isostasy brings about a notable agreement between observation and computation of latitude, longitude, and the intensity of gravity. Hayford, however, favored the interpretation of local and nearly perfect isostasy. In view of the geologic evidence of regional and imperfect isostasy the data were reëxamined. Two chief arguments were developed.

First, the maps of the deflection residuals and gravity anomalies show well-defined groupings within which the signs of the outstanding quantities are alike. These groups are unrelated to the vicinity of sea or mountains, and largely, but not wholly, unrelated to geologic provinces. They indicate regional areas departing to a notable degree from the form of isostasy given by the hypothesis of uniform distribution of compensation. The diameters of the areas of notable departure run up to about 300 kilometers, 200 miles.

The second test of local or regional isostasy consisted in taking pairs of adjacent stations, one of which is below the mean level, the other of the pair above. The algebraic difference of the anomalies should be small for the true hypothesis and large for the false. This test eliminates many of the uncertainties which enter into the calculation of the absolute value of gravity for an individual station, and was applied by the writer to the limited amount of data available. Later he learned that G. R. Putnam, who made important contributions to isostasy in 1894 and 1895, had applied this same test in December, 1912, somewhat more than a year earlier, to Hayford's material, including a pair of stations in Hawaii and another in Switzerland.[14] The number of pairs of suitable stations is limited, but they strongly suggest the existence of regional compensation up to radial distances of at least 167 kilometers.

[14] G. R. Putnam, Condition of the earth's crust, Science, new ser., 36, 869-871, 1912.

Bowie, in 1917, has discussed the effect of the elevation of the station upon the intensity of gravity.[15] Fourteen pairs of adjacent stations were selected which showed a large difference in elevation between the members of each pair. Three of these pairs were in the United States. The algebraic differences of the gravity anomalies under the hypothesis of extreme local compensation are systematic, amounting on the average to 0·0013 dyne for each 100 meters. Bowie shows that by making a more accurate computation of the effect of topography, the systematic difference is slightly reduced; by taking the rock as locally denser beneath the high station than beneath the low one, it is further reduced; by assuming that the compensation does not reach up to the surface, it is still further reduced. By adjusting these factors the differences in anomalies between pairs of stations may be made to disappear. Bowie's argument is sound and valuable; it should be replied, however, that since extreme local compensation cannot be true, the particular algebraic difference of the anomalies which gives a geodetic measure of the error of local compensation should not be made to disappear. Numerous pairs of stations should be measured at different elevations and the corrections for local variations of density should be derived by geologic study. Such pairs would then be better adapted to serve as a geodetic test. Regions of strong local disturbances such as those which prevail near Seattle should, however, be avoided. The problem illustrates the difficulty of purely geodetic tests of various subordinate hypotheses entering into the theory of isostasy.

Bowie, discussing in 1917 the average anomaly given by stations in mountainous regions, finds that regional compensation with a radius of 59 kilometers satisfies the data as well as local compensation, but regional compensation to a distance of 167 kilometers not quite so well. Bowie considers that local compensation is much nearer the truth than this degree of regional compensation. To the writer the adverb "much" appears to be open to question. Mountain regions should, however, show narrower limits for compensation than the areas of low relief. Over the great plains of the continent the anomalies are equally small for local compensation

[15] William Bowie, op. cit., pp. 93-96.

or for regional compensation to a radial distance of 167 kilometers, the greatest distance for which the test was made. It is seen that for such level tracts there should be no distinction between local and regional compensation, since the isostatic adjustment is there due to the elevation of the continental platform above the ocean basins, with a minimum of influence from local relief.

Where marked breaks in topography and geologic structure coincide, it is probable that a rather close relation is to be found to sub-surface density changes. The hypothesis of local compensation takes recognition of such boundaries to geologic provinces, as illustrated by slopes of the oceanic basins and the fault face of the Sierra Nevada. The hypothesis of regional compensation, although truer in general, will, if applied without geologic guidance, result in obscuring such real boundaries.

In Part III of "The strength of the earth's crust," the "influence of variable rate of isostatic compensation" is considered, and evidence given that the anomalies are mostly the measure of real loads, due to irregularities in density in the crust, with little or no relation to the topography formed by erosive processes.

In Part IV, on "Heterogeneity and rigidity of the crust as measured by departures from isostasy," an estimate is made of the magnitudes of the loads due to irregularities of density not in harmony with topography. The largest anomalies thus far found in the United States are those at Seattle. The mean of the two computed values of gravity on the hypothesis of local and uniform distribution of compensation to 113·7 kilometers is 980·830 dynes. The mean of the observed values of gravity is 980·728 dynes. The anomaly is —0·102 dynes. Considering this in connection with the other measurements in the state of Washington leads to an interpretation in terms of mass. It seems that the Seattle anomaly corresponds to a load measured by at least 5,000 feet of rock and may reach a considerably higher figure, perhaps 10,000 feet.

The hypothesis of compensation complete at a depth of 60 kilometers makes these anomalies —0·100 dyne; that hypothesis which assumes compensation complete at the surface, the "Free Air" reduction, gives 0·104, while the hypothesis of no isostasy, the "Bouguer"

reduction, which is equivalent to depth of compensation infinite, gives 0·111. Thus, unless a deficiency of gravity near the surface should be balanced in some wholly improbable manner by an excess at greater depth, there is here a real load, negative in sign but of great magnitude, borne by the strength of the crust. Recent unpublished work by the U. S. Coast and Geodetic Survey shows this belt of deficiency of gravity to extend northward along the east side of Puget Sound, the anomaly at Everett being —0·073 and at Bellingham —0·043 dyne.[16] The deficiencies of density in this region are thus seen to give strains in the crust at least comparable to the excavation of the Grand Cañon of the Colorado.

In Part V the methods for interpreting the geodetic data in terms of mass are further developed and applied in illustration to a region of excess of mass in central Texas, lat. 30°–31°, long. 99°–100°. The data are not adapted to more than a first approximation. The deflection residuals and gravity anomalies indicate, however, an excess of mass whose center of attraction is about 12 miles deep and which is roughly equivalent in load to a cylindrical mass at the surface, density 2·7, height 2,500 feet, diameter 125 miles.

Having developed the evidence of the regionally imperfect nature of isostasy in the previous parts, the point of view is shifted and in Part VI the contrary side of the problem is taken up. The hypothesis of no isostasy introduces large systematic errors into the computations of the deflections of the vertical and the intensity of gravity. The comparison of the maps showing the Bouguer, Free Air, and New Method anomalies gives convincing evidence that not only are continental and oceanic segments fairly closely balanced with respect to density, but such features as the Cordilleran plateaus also. This existence of a high degree of isostasy for areas of broad span throws light on the nature of the crust and subcrust. There must be capable of operation a mechanism of readjustment, necessary when surface agencies destroy to a sufficient degree the isostatic equilibrium. It is shown in this paper, from the distribution of stresses, that the transference of mass must take place in a zone below the depth of isostatic compensation. Furthermore, this zone must be a zone of marked weak-

[16] William Bowie, personal communication.

ness to strains of long duration. The importance of this conception in the larger fields of earth dynamics justifies giving this shell of weakness a special name,—the asthenosphere; the stronger zone of compensation above it constituting the earth's crust, or lithosphere.

In Part VII is taken up "The variation of strength with depth as shown by the nature of departures from isostasy." Conceive the loads on the crust to be of harmonic form, like the form of the broad rollers on the surface of the ocean, as this simplification adapts them to mathematical investigation. Such loads on the surface of a solid give a distribution of stress which has been worked out by G. H. Darwin. The maximum distortional stress below the mean surface is at a depth equal to 0·163 of the wave-length. The distortional stress is nothing at the surface, the load there giving merely hydrostatic pressure. Below the depth of maximum effect the distortional or shear stress rapidly decreases.

The irregular loads ascertained to be held by the strength of the crust as measured by departures from isostasy are then transformed into roughly equivalent harmonic loads. It is found that the large stresses are all in the lithosphere, the asthenosphere being comparatively free from stress. Loads are therefore upheld by the earth in such form as to give stresses on the strong parts of the crust. These results agree with the other evidences regarding lithosphere and asthenosphere.

In Part VIII are discussed "The physical conditions controlling the nature of lithosphere and asthenosphere."

### Sources of Hayford's Errors in Interpretation.

The conclusions as to the perfection of isostasy, as developed in the last topic, stand in contrast to those reached by Hayford. If Hayford's interpretation is wrong, on what false assumptions does it rest? In order to point these out, so far as deflections of the vertical are concerned, the following quotation is given:

"The following table furnishes a measure of the degree of the completeness of the compensation. For a full statement of the meaning of the table and the manner in which conclusions are drawn from it, see pages 164-166 of 'The Figure of the Earth and Isostasy,' etc.

| Region. | Group. | Number of stations. | Mean of topographic deflections without regard to sign. | Mean residual of solution H without regard to sign. | Value in fourth column divided by value in third column. |
|---|---|---|---|---|---|
| | | | " | " | |
| New England ............... | 1 | 58 | 35·60 | 2·76 | 0·08 |
| New York ................... | 2 | 65 | 21·86 | 2·25 | 0·10 |
| New Jersey-Eastern Virginia .. | 3 | 56 | 35·67 | 3·36 | 0·09 |
| Southern Appalachians ....... | 4 | 73 | 22·42 | 2·48 | 0·11 |
| Wisconsin-Michigan .......... | 5 | 52 | 8·96 | 3·73 | 0·42 |
| Ohio Basin .................. | 6 | 67 | 17·77 | 2·40 | 0·14 |
| Missouri-Eastern Utah ........ | 7 | 46 | 16·92 | 2·17 | 0·13 |
| Great Basin ................. | 8 | 42 | 32·23 | 3·57 | 0·11 |
| Northern California .......... | 9 | 60 | 60·50 | 2·93 | 0·05 |
| Coast Range, Southern California | 10 | 57 | 65·44 | 3·91 | 0·06 |
| Florida-Georgia .............. | 11 | 44 | 21·32 | 2·84 | 0·13 |
| Minnesota-Nebraska .......... | 12 | 36 | 8·23 | 2·17 | 0·26 |
| Texas-Oklahoma .............. | 13 | 40 | 19·23 | 3·23 | 0·17 |
| Washington-Oregon ........... | 14 | 37 | 53·68 | 3·37 | 0·06 |
| All combined ............ | | 733 | 30·37 | 2·91 | 0·10 |

"From the evidence shown in the table it is safe to conclude that the isostatic compensation is so nearly complete on an average that the deflections of the vertical are hereby reduced to less than one-tenth of the mean values which they would have if no isostatic compensation existed. One may properly characterize the isostatic compensation as departing on an average less than one-tenth from completeness or perfection. The average elevation of the United States above mean sea level being about 2500 feet, this average departure of less than one-tenth part from complete compensation corresponds to excesses or deficiencies of mass represented by a stratum only 250 feet (76 meters) thick on an average."[17]

This quotation appears to contain two fundamental errors; one in the comparison of topographic deflections with the residuals of solution H, the other in the use of sea level as a datum for interpretations of excesses or deficiencies of mass. The latter error was pointed out and discussed by the writer in 1914.[18] In so far as the relief between continent and ocean floor is concerned,

[17] J. F. Hayford, Supplementary investigation in 1909 of the figure of the earth and isostasy, 59, 1910.

[18] Joseph Barrell, The strength of the earth's crust, Jour. Geology, **22**, 297-301.

the sea level is an unessential surface, valuable only as a datum plane for measuring elevations.

California, for example, is bordered on one side by the Pacific Ocean basin, reaching depths of over 4,000 meters. At about an equal distance on the other side the Sierras rise to over 3,000 meters. The great mass of the Cordilleras lies beyond. It is this larger relief which is the chief cause of the computed topographic deflection, as shown for Point Arena, California.[19] If for group 10, Southern California, the mean effective differential relief is taken as 6,000 meters, the ratio of ·06 corresponds to a departure from isostasy of 360 meters, 1,180 feet. This is very different from the interpretation just quoted from Hayford.

Having noted in 1914 the error due to interpreting the residuals by the use of a sea-level datum, the writer was not looking for another error in the same paragraph. It is evident, however, upon further inspection, that still another of fundamental importance exists which is brought out by comparison with the following table:

"INVESTIGATION IN 1909 OF THE FIGURE OF THE EARTH AND ISOSTASY.[20]

Mean values of residuals without regard to sign, for different depths of compensation.

| Group | Solution B. No isostasy | Solution E. 162·2 km. | Solution H. 120·9 km. | Solution G. 113·7 km. | Solution A. 0·0 km. |
|---|---|---|---|---|---|
| | " | " | " | " | " |
| United States | 9·52 | 2·92 | 2·91 | 2·98 | 3·88 |
| 1 | 12·73 | 2·69 | 2·76 | 2·80 | 2·99 |
| 2 | 8·14 | 2·16 | 2·25 | 2·27 | 3·64 |
| 3 | 4·72 | 3·36 | 3·36 | 3·36 | 3·43 |
| 4 | 4·67 | 2·52 | 2·48 | 2·48 | 2·88 |
| 5 | 4·66 | 3·71 | 3·73 | 3·74 | 4·22 |
| 6 | 4·89 | 2·39 | 2·40 | 2·40 | 2·50 |
| 7 | 15·70 | 2·15 | 2·17 | 2·20 | 4·64 |
| 8 | 10·31 | 3·92 | 3·57 | 3·51 | 4·19 |
| 9 | 10·67 | 2·73 | 2·93 | 2·96 | 4·62 |
| 10 | 16·09 | 3·99 | 3·91 | 3·91 | 6·48 |
| 11 | 8·42 | 2·84 | 2·84 | 2·85 | 3·05 |
| 12 | 11·82 | 2·09 | 2·17 | 2·19 | 2·78 |
| 13 | 16·12 | 3·25 | 3·23 | 4·30 | 4·62 |
| 14 | 10·34 | 3·64 | 3·37 | 3·33 | 5·13" |

Solution B is the hypothesis of infinite depth to compensation, that is, the density is assumed horizontally uniform in the crust giving no isostasy. Solution A

[19] See J. F. Hayford, The figure of the earth and isostasy from measurements in the United States, 32, 1909.
[20] J. F. Hayford, Supplementary investigation, 56, 1910.

assumes that the relief of the earth is neutralized by compensation at the surface, in other words, that topography has no influence on the deflections of the vertical.

Instead of comparing the residuals of the several solutions with each other, Hayford has taken the ratio of the mean residual of solution H to the mean topographic deflection as a test of the value of isostasy. The ratio of the mean residual to the mean topographic deflection might almost as well be used as a proof of the absence of isostasy, since it is observed that solution B, no isostasy, gives a mean residual for the whole United States which is less than one-third of the value of the mean topographic deflection. There is much less difference between these residuals than there is between them and the mean topographic deflection.

The topographic deflection is not a direct measure of the discrepancy due to the hypothesis of no isostasy, as Hayford has here used it. There the observed deflection must be subtracted algebraically from the topographic deflection, and then further corrections made, due to errors in the initial longitude, latitude, or azimuth, also to the initial radius of the earth, and the square of the eccentricity. The corrections are notable quantities serving to materially change the value of the residuals. They are the unknowns derived from the normal equations into which all the observations enter, and have a different value for each hypothesis regarding isostatic compensation. It is true that the value of these corrections as given by solution B does not agree with the values obtained from some other lines of evidence as well as do the corrections obtained from solutions E, H, or G, but that is to one side of the present argument.

It is seen that for the eastern United States removed from the seaboard, especially groups 3, 4, 5, 6, the residuals of solutions H and G are one-half to three-quarters as large as those of solution B, no isostasy. This is a clear indication that irregularities of density not related to topography have more influence upon the deflections than the topography of the lands east of the Mississippi. This feature is especially striking in the Lake Superior region, group 5, but is almost as notable in the southern Appalachians, group 4. In Southern California, group 10, many of the stations are near the coast. Here the influence of the larger features of the earth is at a maxi-

mum for the United States, and the residuals of solutions E, H, and G are only one-fourth those of solution B.

It would appear, therefore, that continents rest nearly in isostatic equilibrium with respect to ocean basins, and that the larger features of the continents also show very considerable adjustment between regional elevation and density, but the evidence from deflections of the vertical as presented by Hayford does not prove, as he thought it did, a close local isostatic relationship. On the contrary, it shows the importance of density variations unrelated to topography. It is clear that geodetic investigations pursued with competent geologic coöperation are capable of revealing the larger and deeper structures of the crust to a degree which has heretofore never been appreciated, and this should be recognized as a new and important means of geologic research.

It is impossible, however, to utilize to a large extent for geologic problems the geodetic data as now published, since, in the published results, the items which enter into the topographic deflection and the effects of various depths of compensation are not listed except for a few illustrative stations. A complete publication would make a volume of perhaps a thousand pages, but the size of a work has not customarily been an argument against publication in the government printing office and such a volume would make a valuable permanent record of source material.

If such details were given, one page of tabulated figures for each station, it would be possible to try out various hypotheses. For example, in the Lake Superior region, group 5, it might be found, by comparing various stations, to what degree the compensation was local or regional and something further in regard to the location of masses of excessive density. The outstanding masses are so large, and the distance from the ocean basins so great that the data do not show strong evidence of isostasy. Just for that reason, however, they would serve as a means for determining the larger irregularities of crustal density in a region where knowledge has become of high theoretic and economic importance.

There remains to be mentioned the interpretation of gravity anomalies. This was discussed by the writer in 1914 and that detailed analysis need not be repeated. Hayford and Bowie estimated that the mean anomaly

corresponded to a mean departure of the surface of the United States of about 500 feet from the level-giving equilibrium, as many stations being positive as negative. Later Bowie raised this estimate to 630 feet. They recognize that it is difficult to give an accurate estimate. Under assumptions equally or perhaps more probable, however, the interpretation could be made 1,000 to 1,400 feet. The maximum anomalies indicate loads several times as great. These departures from isostasy are regional in extent, the larger loads being restricted to smaller areas than are the lesser loads.

Notwithstanding this lack of perfection in isostasy, the gravity anomalies prove with great conclusiveness the existence of regional isostasy to a notable degree. This is best brought out by the map of gravity anomalies for the United States as given by the Bouguer reduction, which postulates no isostasy. The map shows large and systematic errors introduced by this hypothesis, the errors increasing with the elevation above the datum plane. On comparing two stations, the influence of the datum plane is eliminated and the discrepancy is seen to depend largely upon the difference in regional elevation.

## Interpretations Adverse to Isostasy.

Hobbs in 1916 contributed an article to the subject of isostasy.[21] In criticism of Hayford's attitude toward the geological interpretation of the geodetic data, he cites examples which teach that although the methods of exact science may not be lacking in precision, the assumptions possess the same measure of fallibility as those employed in other fields of science. Hobbs then shows that along the Atlantic and Pacific mountain belts and near the coasts the observed deflections of the vertical *due to topography* are large, and are in the general regions of strong seismicity. The arrangement of the belts of seismicity and of high deflections along distinct lines is no doubt in part due to the direction of rock structures, but to the writer it appears to be due in part also to the fact that observations are more numerous in or near the large centers of population. These last in turn are associated with certain lines, such as the fall

[21] W. H. Hobbs, Assumptions involved in the doctrine of isostatic compensation, with a note on Hecker's determination of gravity at sea. Jour. Geology, 24, 690-717, 1916.

line, marking the head of navigation in the east, and the valleys of the Pacific coast states. Both large deflections and strong seismicity, however, mean local earth strains, so that such an association is natural. The relationships are worthy of further study. If there are such relationships, they still do not in the least invalidate the evidence bearing on isostasy, as Hobbs's use of the data seems to imply. On the contrary, although the gravitative effect of the relief is large in these regions, giving the large *topographic* deflections, the observations show the *actual* deflections to be small. The introduction of the hypothesis of isostasy, by offsetting the effect of the relief, brings the calculated deflections into agreement with the observed, and it is therefore just these regions which offer the best proof of the existence of isostasy.

Hobbs extends his argument (pp. 698-701) to an attempt to invalidate the whole solution of the problem by Hayford. His reasoning turns on several points. The most important is that we know nothing concerning the distribution of mass beneath the earth's surface, and that adjacent masses must exert a preponderant effect.

To the writer this argument appears to be successfully answered by the results. It is granted that at the beginning of the investigation we know nothing of the distribution of mass, since it is the problem to be solved. Introduce a general hypothesis, such as that of isostatic compensation. If, under this hypothesis, the many calculated deflections of the vertical and intensities of gravity agree closely with the measurements, the agreement indicates that the hypothesis is a *working hypothesis*. The hypothesis should then be varied to see how many kinds will survive as working hypotheses and what kinds must meet the fate of the unfit. The working hypotheses, both for deflections and for gravity, are all found to agree in this common feature,—that regional elevations and depressions correspond rather closely to regional defects and excesses of density within the outer fiftieth of the earth's radius. The probability that this represents the truth increases with the variety of data tested and with the repeated failure of attempts to establish a successful counter hypothesis. Plausible counter hypotheses have been set up, but like plans for perpetual motion machines, they have not been made to work. Isostasy as a working hypothesis agrees with most of the data very closely,

with some observations not closely. On the average, as previously stated, it accounts for nine-tenths of the deflections and gravity abnormalities to be explained, leaving only one-tenth as residuals and anomalies. It is true, as Hobbs states, that near masses have preponderant effects, and such near masses not in agreement with isostasy account for a considerable part of the deflection residuals and gravity anomalies. The data are as yet too coarse to measure many of the masses, but the writer has tested the matter for certain regions and reached a first approximation.[22] It would appear that the theory of isostasy has more than justified itself, and that, as a result of its application, we are coming to know something, instead of nothing, concerning the distribution of mass beneath the earth's surface.

Hobbs states that Hayford's explanation of anomalies rests on an assumed systematic regularity as contrasted to local irregularity in distribution of mass, and implies that the residuals are made to disappear by a process of averaging. It may be replied that the test by the method of least squares is by no means a process of causing residuals to disappear by averaging. The process, on the contrary, is one of making the individual residuals become small by finding that law by which calculation and observation come nearest to agreement. Hobbs's argument implies that a small local mass of high positive or negative density could be placed near each station so as to give the observed deflection or intensity of gravity at that point without affecting the other stations, in this way simulating the influence of systematic isostatic compensation. When the number of stations is considered, it is seen that the appropriate location of such local masses would call for an amount of creative design to delude mankind comparable to that sometime theological argument that fossils were created to mislead those who should be guilty of undue prying into the secrets of nature.

In 1917 W. D. MacMillan contributed a paper entitled "On the hypothesis of isostasy."[23] This is a brief paper, for one covering so large a subject. Its attitude is that of skepticism toward any specific form of isostatic theory and of destructive criticism toward the one employed by

[22] Joseph Barrell, The strength of the earth's crust, Jour. Geology, 22, 302-314, 441-468, 537-555, 1914.
[23] W. D. MacMillan, Jour. Geology, 25, 105-111, 1917.

Hayford. Its points, however, seem to the writer poorly taken. The statements are mostly general, there is an absence of demonstration, and the whole article serves more to befog than to elucidate the subject. It would hardly be necessary to review this paper were it not for the fact that it was published in a leading geological journal and was written by a mathematician for geologists.

MacMillan concedes in the introductory statement that the geodetic data have placed "the hypothesis of isostasy upon a solid foundation of credibility," but considers that it is not proved and "that with a slight modification of the hypothesis the 'depth of compensation' could be made to retreat to the center of the earth or vanish altogether."

The concluding paragraph of his article states:

"While the theory of isostasy has made a very successful approach to the solution of the problem of bringing the anomalies of observation into accord with the theory of gravity, it must be admitted that there is no evidence to show that the solution of the problem is necessarily isostatic."

MacMillan does not offer any non-isostatic solution, or even constructive criticism, but dwells on the fact that changes of assumption in regard to the distribution of compensation give different depths of compensation, and that an infinite number of solutions could be made.

MacMillan is apparently unaware of the existence of other analyses of Hayford and Bowie's work, even of those published in the same journal as his article. For example, he makes, as though they were new discoveries, some general adverse comments on Hayford's interpretation of gravity anomalies in terms of thickness of rock,[24] although the writer had discussed this topic specifically and in varied related aspects.[25] MacMillan's article in fact suggests a rather superficial knowledge even of Hayford's work. Two general topics which he discusses as involving fundamental errors it will be necessary to amplify here under separate topics in order to show what are the difficulties and to what degree they affect the conception of isostasy. In both cases there is found to be no basis for his criticisms.

[24] W. D. MacMillan, op. cit., pp. 110, 111.

[25] Joseph Barrell, op. cit., pp. 297-301; also parts IV and V, pp. 289-314, 441-468, 537-555.

## Influence of Datum Surface on the Theory of Isostasy.

The hypothesis of isostasy stated in general terms is seen to be that the relief of the earth is balanced to a large degree by variations in density in the crust. To subject this hypothesis to mathematical tests certain conventional assumptions must be made. If it can be shown that these assumptions involve reasoning in a circle, or if a permissible and alternative change in assumption brings about a radically different solution, then the

Fig. 2.

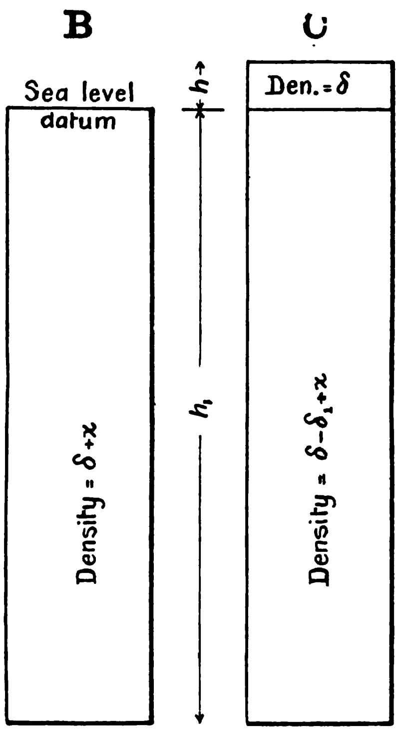


Fig. 2. Assumed relations of elevations to isostatic compensation.

mathematical evidences of isostasy based on such assumptions are invalid. If, on the other hand, the assumptions, irrespective of reasonable changes, give consistent solutions, then such solutions, although not exactly representing nature, still give the limits within which the actual conditions must vary.

Let $h$ be the elevation of a topographic feature above sea level and $\delta$ the mean density of the outer few miles of the crust. Then, disregarding local variations of density in the surface rocks, the mass of the unit column above sea level is $\delta h$, as shown in C, figure 2.

Let $h_1$ be the depth of compensation measured below sea level. As it extends downward 100 kilometers, more or less, and as density increases toward the center of the earth, its mean density will be presumably somewhat greater than $\delta$. For the column such as B, whose surface is at sea level, let this mean density be $\delta + x$.

Then in column C, to maintain the equality of mass with B, there must be a defect of density below sea level represented by $\delta_1$, so that $\delta_1 h_1 = -\delta h$, a constant.

Therefore $\delta_1 = -\delta \frac{h}{h_1}$.

The mean density of column C is, then, $\delta \left(1 \frac{h}{h_1}\right) + x$

For convenience in computations, the defect is taken as extending from the surface through a uniform depth instead of from sea level. This gives the surface at the bottom of compensation the form of the upper surface of the crust, the difference between the two assumptions being found immaterial in the results. This is as it should be, for neither the regular or irregular form of the bottom surface can be regarded as representing the conditions of nature.

The sea level, however, is a wholly arbitrary surface, so far as isostasy is concerned. It is merely a convenient datum from which positive (land) and negative (sea) elevations may be measured. What, then, would be the influence on the results if another datum surface were selected? This is a subject not discussed by Hayford or Bowie. MacMillan enlarges upon the fact that Hayford chose as his datum surface the sea level, instead of a datum representing the mean surface of the earth, which would be 9,000 feet below sea level. To show the sophistry of this reasoning, in so far as the geodetic computations are concerned, the following figure is drawn for the present article, MacMillan giving no diagram or detailed analysis:

Let A, B, C, D be four unit columns of the crust. The top levels of the columns are taken at —9,000, 0, +1,000,

and +6,000 feet measured with respect to sea level, these being the elevations by which MacMillan illustrates his argument. Under the theory of isostasy each column has the same mass.

The unknown to be sought is the depth of compensation, $h_1$, under the assumption of a uniform distribution of the compensation, and the test of the solution is to see if the calculated deflections of the vertical and the

Fig. 3.

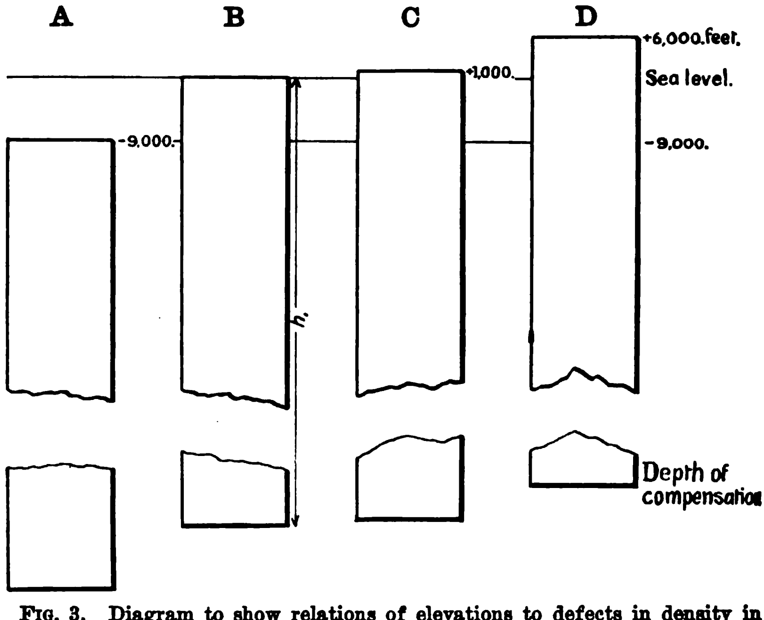


Fig. 3. Diagram to show relations of elevations to defects in density in accordance with the hypothesis of uniform vertical distribution of isostatic compensation through a constant depth of crust.

intensities of gravity are by this ascertained depth of $h_1$ made to agree closely in a great mass and variety of data with the observed values. As a matter of fact, Hayford and Bowie's results, as is well known, reduced the discrepancies on the average to one-tenth of the effect of the topography without compensation. What, then, would be the effect of changing the datum plane from sea level to the mean surface of the geoid, 9,000 feet below? Will such change give another value to the depth of compensation or to the deflection calculated from that depth?

On a lowering of the datum surface by 9,000 feet, the mass of every column above the datum becomes $\delta\ (h + 9{,}000)$, instead of $\delta h$. Substituting $h + 9{,}000$ for $h$ in the equation giving the defect of density below sea level gives,

$$\delta_1 = - \delta \frac{h + 9{,}000}{h_1}.$$

For convenience place $\frac{\delta}{h_1} = \text{m}$, and write

$$\delta_1 = (h + 9{,}000)\ \text{m}$$

For columns A, B, C, D the relative defects of density for change of datum may then be tabulated as follows:

*Relative defects of density for change in datum by 9,000 feet.*

| | Columns, fig. 3. | | | |
|---|---|---|---|---|
| Datum | A | B | C | D |
| Sea level ..... | +9,000 m | 0 | —1,000 m | —6,000 m |
| —9,000 feet ... | 0 | —9,000 m | —10,000 m | —15,000 m |

MacMillan points out that for the sea level datum the defect of density is six times as great for column D with elevation of 6,000 feet as it is for C with elevation of 1,000 feet; whereas for the datum at —9,000 feet the defect under D is only 1·5 times as much as under C. He gives, further, a table to show how enormously the ratios are changed by selecting other reference surfaces. So far as the writer can see, this argument involves a sophistry in that it dwells on the *ratio* of these defects as compared to a column whose surface is at sea level. In the determination of the deflections of the vertical it is not, however, the ratios, but the *differences* of the defects in the different columns which measure the deflections of the vertical. It will be observed that the difference of defect between C and D is 5,000 m irrespective of datum, and that between A and D is 15,000 m, corresponding to the differences in elevation. MacMillan also raises the objection that variations in the datum, by changing the absolute values of the defects of density, change the resulting specific gravities, and calls this a *reductio ad absurdum*. Here again the argument is to one side and sophistical, since the hypothesis of isostasy postulates nothing in regard to the density of any shell below the sea bottom, as indicated by the insertion of $x$ in figure 2.

Isostasy is concerned only with the *differences* of density under different horizontal areas corresponding to their *differences* in elevation. Small errors in the specific gravity of the relief of the earth's surface give rise merely to small corrections which have been discussed by both Bowie and the writer.

A critic should take the trouble to prove his criticism, not leave it as a doubt to unsettle those who cannot be expected to prove or disprove it. The assumption of a datum at —9,000 feet is equivalent in the problem of deflections to increasing all elevations 9,000 feet. Such an assumption is readily applied to the examples of computations of topographic deflection.[26] The topography surrounding the station is covered by a series of annular zones or rings whose centers are at the station. Each ring is divided into compartments. The compartments are so taken that for a unit mass in the compartment each has a unit effect in deflecting the vertical in the plane of the meridian or prime vertical. For each compartment the increase of elevation by 9,000 feet increases the deflection 0·9″, but in the sum of the compartments of any one ring, the half on one side pull one way, the half on the other side pull the other way, and it is difference of masses which alone has effect. The constant increase of 0·9″ for each compartment, due to change of datum, therefore cancels out. The deflection due to the *compensation* as distinct from the topography is obtained by multiplying the deflection due to topography by a reduction factor which varies with the horizontal *distance* from the station but does not involve the *elevation* of the station.[27] Thus, change of datum, on direct application to the illustrative problems, is observed to have no effect in the result.

The influence of change of datum upon the computations of gravity remains to be considered.

Let the intensity of gravity at any station be computed under the assumption of isostasy according to Hayford and Bowie's method, using the sea-level datum. The mass of each unit area to be compensated is $\delta h$, in which $\delta$ is mean surface density and $h$ the elevation. Next assume a new datum, 0 — 0, figure 4, at a depth $c$ below the initial datum. The elevation of each unit area now

[26] J. F. Hayford, op. cit., pp. 26-33, 1909.
[27] J. F. Hayford, op. cit., pp. 68-73.

becomes $h + c$, in which $h$ as before is variable, positive or negative, and $c$ is a constant. The total mass to be compensated with the new datum becomes $\delta\ (h + c) = \delta h + \delta c$, the new or added mass is $\delta c$, which is independent of $h$. It is compensated by an equal deficiency of mass, $-\delta c$, assumed to be spread over the whole depth of compensation. Consider this effect in a cylinder of the

FIG. 4.

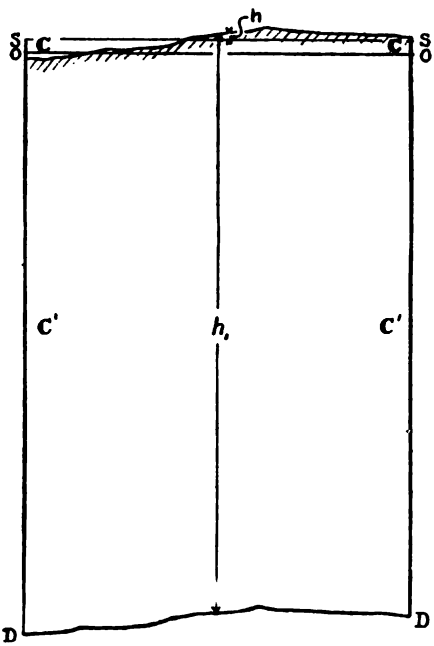


FIG. 4. Diagram to illustrate influence of change of datum on composition of gravity.

crust of limited radius, whose axis is the vertical passing through the station, as shown in figure 4. It is seen that the center of gravity of the added shell is near the station, that of the compensation lies far deeper, at half the depth of compensation. Since their gravitative effects vary inversely with the square of the distance of each unit particle, the added mass below the station increases gravity more than the equivalent compensation decreases it. For a small cylinder, the lowering of the datum consequently increases the computed value of gravity. For a cylinder of larger radius, the outlying

portions of $c - c$ have but little influence on the intensity of gravity, since their attractive forces act nearly horizontally. The added compensation, however, being more nearly under the station, serves to offset the excess due to $c$ in the smaller zone. Next let the whole earth be considered. The excess of mass, $cc$, and its compensation, $c' - c'$, now become spherical shells. But the gravitative force of a spherical shell acts on any outside station the same as if its matter were concentrated at the center. As the masses $c - c$ and $c' - c'$ are concentric and equal in magnitude, but positive and negative in sign, they exactly neutralize each other. Therefore when the whole earth is considered the influence of change of datum cancels out. In Hayford and Bowie's work the whole earth is considered; consequently, change of datum does not produce any effect on the computation of gravity under the hypothesis of isostasy.

### Distribution of Isostatic Compensation.

The solutions of the geodetic data do not give a sharply defined depth to isostatic compensation. They show unmistakably that such compensation does exist, but on the assumption of uniform distribution, the most probable depth ranges from 60 to 300 kilometers according to the regional group of data taken. The largest depths are the least reliable, and Bowie believes that the mean given by much more extensive data will fall between 80 and 130 kilometers. For the present he takes 96 kilometers as the most probable depth. Round figures have an advantage in that they do not imply an accuracy which does not exist. On the assumption of uniform distribution, 100 kilometers, 60 miles, may therefore be taken as the most probable general depth.

The next question is, as to how the compensation really is distributed and how much it may vary in its mode of distribution. Figure 5 shows several modes which satisfy equally well the deflection data, giving an equally small minimum to the sum of the squares of the residuals. The computations on which the diagrams are based are given by Hayford,[28] with the exception of the center of gravities of distributions C and D, which were determined by the writer.

[28] J. F. Hayford, op. cit., pp. 149-163.

These diagrams are based on the solution of 1909 which gave 113·7 kilometers, 70·7 miles, as the most probable limiting depth under the hypothesis of uniform distribution. They are directly and accurately comparable with each other, although, as previously explained, there is no especial importance to be attached to the value of 70·7 miles.

First, assume that the compensation is confined to a stratum 10 miles thick. A couple of trial solutions showed that to give the same minimum to the sum of the squares of the residuals the bottom must be at a

FIG. 5.

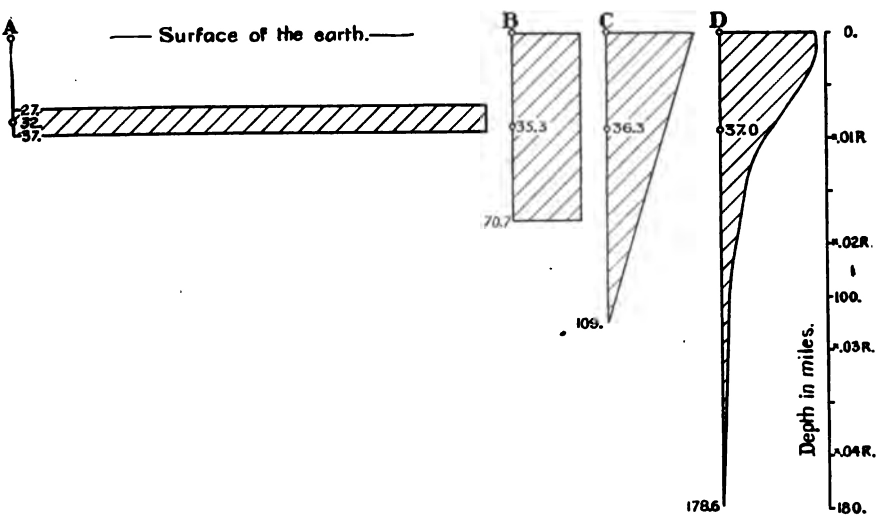


FIG. 5. Several distributions of isostatic compensation which satisfy equally well the deflection data, showing center of gravity of the distributions.

depth of 37 miles, as shown in A of figure 5. The center of gravity is consequently at a depth of 32 miles.

Second, let this 10-mile stratum be expanded until its top reaches sea level; the bottom will lie at a depth of 70·7 miles, shown in B. The center of gravity has descended from 32 to 35·3 miles.

Third, let the assumption be adopted that the amount of compensation is a maximum at sea level and decreases uniformly with depth until it becomes zero at the limiting depth. This compensation, expressed graphically as a triangle, is shown in C of figure 5. The limiting depth is found to be 109 miles.

Fourth, let the assumption be adopted that the compensation extends to a greater depth than in the uniformly decreasing manner. T. C. Chamberlin proposed this as a solution which seemed equally or more probable to him than that which postulated uniformly distributed compensation.[29] Hayford accordingly solved the abscissas of a curve of the character suggested by Chamberlin, the requirements of the solution being that the distribution of the compensation must satisfy the deflection data as well as the other solutions. He thus gave Chamberlin's qualitative suggestion quantitative expression. A first trial solution made the limiting depth 141·3 miles, a second made it 201·5 miles, and a third and closest approximation gave 178·6 miles as shown in curve D, figure 5.[30]

These four equally probable solutions, A, B, C, D, figure 5, show, in the order given, increasingly great depths for the limit of isostastic compensation. This increase shown is the basis for MacMillan's sweeping statement "that with a slight modification of the hypothesis the 'depth of compensation' could be made to retreat to the center of the earth or even to vanish altogether." It appears, for example, that the assumption might be made that the compensation extends to a depth of 1,000 miles before it vanishes, and a curve calculated to fit the assumption. The question to be asked, however, is, if such an assumption has any geological application or if it would be as unreal as an algebraic solution leading to an imaginary root. As a test of the nature of the distribution of the compensation under hypotheses A, B, C, and D, let the proportion above 32 miles and the proportion above the center of gravity of each solution be determined. These ratios are tabulated as follows:

*Hypotheses of isostatic compensation showing comparative distribution.*

A. Compensation confined to a 10 mile stratum.
B. Compensation uniformly distributed.
C. Compensation uniformly decreasing.
D. Type of compensation extending to great depth.

[29] Jour. Geology, 15, 75-78, 1907.
[30] J. F. Hayford, op. cit., pp. 159-163.

*Comparative distribution of compensation.*

| | A | B | C | D |
|---|---|---|---|---|
| Depth of center of gravity, miles... | 32·0 | 35·3 | 36·3 | 37·0 |
| Depth of bottom, miles ........... | 37·0 | 70·7 | 109·0 | 178·6 |
| Percentage above 32 miles ........ | 50·0 | 45·2 | 50·1 | 57·2 |
| Percentage above center of gravity | 50·0 | 50·0 | 55·5 | 63·1 |

It is observed that the center of gravity would be highest for compensation reduced to an indefinitely thin plate. The center of gravity for that assumption would lie at a depth of between 31 and 32 miles. Under the hypothesis of uniform distribution through the thickest possible shell compatible with the least squares, the center of gravity would descend, as shown in B, about 4 miles to 35·3 miles. Of course, a much thicker shell might be arbitrarily assumed, but the sum of the squares of the residuals between the computed and observed deflections would be much larger with increasing depth, a clear indication that such an assumption has no application and must be rejected.

Under the hypothesis of uniformly decreasing compensation, the center of gravity is at a depth of 36·3 miles, an increase of only one mile over the center of gravity of the uniform compensation, but the compensation does not vanish until a depth of 109 miles is attained. This extension of nearly 40 miles in depth is offset, however, by an increase in the proportion of the compensation above the center of gravity, and especially near the surface.

In the compensation extending to great depth, curve D, when this depth is taken as 178·6 miles, it is seen that because of the greater depth a still larger proportion of the compensation lies between the surface and 32 miles than in the other three type solutions. Furthermore, although the vanishing point has descended 70 miles below that for uniformly decreasing compensation, the center of gravity has descended less than one mile, and 63 per cent. of the compensation now lies above the center of gravity.

From this series of four cases we may deduce what would be the effective distribution of compensation if it were assumed to extend to still greater depth. The center of gravity would only descend slightly. Probably it would not be over 38 miles deep if the compensation

were assumed to extend to the center of the earth. A still larger proportion of the compensation would lie above the center of gravity, and the portion of the curve below the center of gravity would become much more attenuated than in curve D, fig. 5. At depths below the center of gravity, the compensation would approach the vanishing mass of a mathematical line, and as such could be extended indefinitely. Even for curve D, in fact, where the limiting depth is taken as only 178·6 miles, but 5 per cent. of the compensation lies below a depth of 107 miles. For a greater assumed extension in depth, a still smaller proportion of the compensation would be found to lie below a depth of 107 miles.

The geodetic data which gave the solutions shown in figure 5 could be made to yield an infinite number of solutions, but beyond certain limits these would have no geologic meanings and become simply mathematical exercises. It is appropriate next to inquire regarding the limits within which lie the geologic possibilities.

Disregarding the small amounts of unconsolidated sediments or molten magmas which may lie in the crust, the specific gravities of the principal rock types may be taken as follows:

| *Rock* | *Specific Gravity* |
|---|---|
| Granite | 2·63–2·75 |
| Syenite | 2·6 –2·8 |
| Diorite | 2·8 –3·1 |
| Dolerite | 3·0 –3·3 |
| Limestone | 2·6 –2·8 |
| Sandstone | 2·5 –2·7 |
| Shale | 2·4 –2·8 |
| Slate | About 2·8 |

The mean density of the rocks which underlie the continents to a depth of several miles may be taken at 2·70 to 2·75 as a minimum.

The mean elevation of the continents may be taken as 2,400 feet, the mean depth of the sea as 13,000 feet. If the sea water is imagined transformed into rock and the bottom of the dry ocean beds raised accordingly, the mean depth of these would become 8,000 feet instead of 13,000 feet. The mean relief between continents and ocean basins to be supported by isostatic compensation becomes, consequently, 10,400 feet or 2 miles. Consider-

able areas, however, would have a differential elevation of 3 miles.

Take two areas of the crust with a difference in elevation of 3 miles, the higher having a density of 2·72 for a depth of 3 miles. What difference in crustal densities will be required to support these two areas in isostatic equilibrium? The answers may be tabulated as follows:

*Relations of isostasy to density.*

| Distribution of compensation, Fig. 5 | Difference in densities to support relief of 3 miles with density 2·72 | Maximum suboceanic density, subcontinental being taken as 2·80 |
|---|---|---|
| A | 0·81, from 27 to 37 miles | 3·61 |
| B | 0·115, from 0 to 70·3 miles | 2·91 |
| C | 0·15, at surface | 2·95 |
| D | 0·165, at surface | 2·96 |
| | 0·014, at 100 miles | 2·81 |

As the effects of temperature and pressure may be taken as roughly the same at equal depths under continents and oceans, those factors influencing density may be neglected.

It is seen that compensation confined to a 10 mile stratum requires an excess of density to the oceanic portion of the stratum 0·81 greater than the density of the continental portion where the differential relief is 3 miles. At depth of 27 to 37 miles the subcontinental crust cannot be less dense for surface conditions than 2·80. It may be 3·00. This would give 3·61 or 3·81 for the suboceanic rock, types unknown at the surface of the earth. As igneous activity brings up material from great depths, this is wholly improbable. The geodetic evidence ruled out the possibility of variable density serving to maintain isostasy in a 10 mile stratum close to the surface, or at a depth of 60 miles, by showing that its center of gravity would have to be not far from 32 miles deep. The geologic evidence based on known densities excludes this form of isostatic compensation, or even compensation restricted to a 20 mile stratum at any depth. Thus the argument from densities shows that solutions giving such a stratum are imaginary. So far as the known range of densities gives testimony, B, C, and D, figure 5, are readily possible, but A is impossible.

Let attention be given next to the real or imaginary nature of curve D.

The broad areas recently subjected to continental glaciation are observed to be in a depressed condition, greatest where the ice was thickest. The present departure from equilibrium must presumably give, in those regions, an upward strain resisted by the strength of the crust and subcrust. The stability of a continent during a partial cycle of erosion implies the same resistance to upwarping forces as does the persistence of a depressed condition after glaciation. The Nile and Niger deltas, on the other hand, show the capacity of the crust to resist downward stresses. Irregularities in density not related to the topography give indications of being comparable in magnitude of loads to mountains, and these to be supported through geologic ages by the strength of the crust.

Mathematical solutions of isostatic compensation depending on differences of density of the order of 0·01 therefore have no geologic meaning. In D, the curve of compensation extending to 178·6 miles, everything below 100 miles may therefore be dropped so far as the geodetic evidence and the geological argument are concerned. If such slight uniform differences of density exist at those depths between continental and oceanic sectors, they exist irrespective of the geodetic and geologic evidence. It is much more probable that the differences of density at such depths are larger, more irregular than the curve, positive and negative, and unrelated to isostatic compensation. The slender portion of curve D below 100 miles is consequently nothing more than an abstraction, serving as a tail to which to tie a mathematical argument.

Having eliminated for good geological reasons curve A and the lower part of D, it may be seen how poorly taken is MacMillan's argument, based on curves A, B, C, and D, that with a slight modification of the hypothesis the depth of compensation could be made to retreat to the center of the earth or vanish altogether.

It may be stated in conclusion that the isostatic compensation balancing continents against oceans, if corresponding to the depth of 70·7 miles for uniform distribution, must have its center of gravity between 34 and 37 miles deep, but may be of any mode of distribution, so long as the density differences do not exceed a reasonable amount at any depth and the whole

effective compensation is above a depth of 100 miles. There are here an infinite number of gradations, but they are restricted within definite limits, and the several types shown in curves B, C, and the upper part of D may be taken as representative.

It is seen that the hypothesis of uniform distribution, curve B, is the simplest mathematically and readily converted into distributions C and D. It is therefore a convenient form for using with the geodetic data. It is not, however, for that reason more probable. In fact, the indications are that C is more probable than B, and D minus the tail may be better than C.

The preceding discussion has been based on the solution which gave 113·7 kilometers, 70·7 miles, as the most probable depth for compensation if uniformly distributed. The later results have decreased this to 100 kilometers, 60 miles, and the compensation is brought that much nearer to the surface. There appear to be good reasons, however, partly geodetic, partly geologic, for regarding the depth as notably different in different regions. For example, in Hayford's publication of 1909 on deflections of the vertical, group 8, including parts of Utah, Nevada and California, indicated, on the basis of 42 residuals, a depth of compensation much less than that of the central United States. The same appears as the result of Bowie's latest discussion of the anomalies of gravity. On the geologic side it is seen that the great Cordilleran plateaus have in recent geologic time been the seat of regional igneous activity and block faulting on a vast scale. Intrusions of magma and the heat which must accompany them have set apart the Cordilleran province from the regions of geologic quiet, and may have decreased the densities in the outer crust sufficiently to account for the recent regional elevation above its own former level and the present level of other portions of the continent. The intra-continental compensation may therefore be of a different nature and developed at a higher level than the compensation which separates continents from oceans.

In conclusion, the density of the crust is presumably irregular in depth as well as in distribution, but it is seen to be essentially a phenomenon of the outer fiftieth of the earth's radius. The density variations which lead to the major reliefs of the surface are merely dermal features disconnected with the great body of the earth.

## Isostasy in India.

India is the birthplace of the hypothesis of isostasy, through Archdeacon Pratt showing in 1855 that the Himalaya mountain system deflected the vertical at stations near the mountains much less than should have been the case in view of the mass of matter above sea level. It was pointed out by Airy that the simplest explanation lay in the assumption that the crust below the mountain system was less dense than that beneath the plateau of India.

The comprehensive scope of the geodetic and topographic survey of India enabled Crosthwait in 1912 to apply the Hayford method of computation to the data on the deflections of the vertical.[31] His investigation showed that, under the Hayford hypothesis of uniform compensation to depth of 113·7 kilometers, the mean difference between calculated and observed deflections for India is 5·1″. The regions of very high residuals are in Region No. 1, in the foothills of the Himalayas, where the mean residual is —16″, and Region No. 3, northeast India, consisting of the broad alluvial basin of the Ganges and bordering upland to the south, where the mean residual is +8″.

Crosthwait concludes that isostatic conditions are much more nearly realized in America than in India, as judged by the size of the residuals, and points out the probable cause in the great mountain-building forces which in recent geologic times have given rise in the north of India to the culminating range of the whole surface of the globe.

These discrepancies with the particular hypothesis of isostasy adopted by Hayford have received various interpretations. Col. S. G. Burrard has made them the basis of a geological interpretation[32] which contains such apparent improbabilities as to be impossible of acceptance without better proof than has yet been submitted.

H. H. Hayden has tested the data by assuming other depths of compensation, and has found that among several solutions the mean of the computed deflections approaches closest to the observed deflections if the compensation beneath the Himalaya extends to a depth

[31] H. L. Crosthwait, Investigation of the theory of isostasy in India, Prof. Paper No. 13, Trigonometrical Survey of India, 1912.

[32] S. G. Burrard, On the origin of the Himalaya mountains, Prof. Paper No. 12, Trigonometrical Survey of India, 1912.

of 330 kilometers, and under the plains in front, to a depth of 60 kilometers. The sums of the residuals were reduced to the smallest amount if the depth of compensation was taken at 600 kilometers in Western India, 330 kilometers in Eastern India, and at the surface in Southern India.[33] The solutions, however, show indeterminate results in several of these cases, in that there are two minima to the sum of the residuals for increasing depths of compensation. Hayden notes that the number of stations is too few to give reliable averages, but considers it as probable that the conditions beneath the Himalaya are in reality different from those beneath the other provinces of India. The results also point out what is evident from the United States, that other variations from the condition of perfect isostasy are of more influence upon the residuals than assumed variations in the depth and distribution of compensation. Hayden reached a conclusion similar to that of Crosthwait: that the problem of isostasy in India is much more complicated than in the United States. Hayden finally considers the evidence from the intensity of gravity, and concludes from the deficiencies over the plains that the trough filled by the Indo-Gangetic alluvium is a broad basin sloping gently inwards toward the Himalaya, from which it is separated by a steep wall resulting from the series of reversed faults which separate the older geological systems from the younger.

The interpretation has thus far brought forth a probable great depth of compensation beneath the Himalaya, permitting an isostatic support of the great mountain masses without requiring very great differences in crustal density; an alluvial trough depressed in front of the mountains and filled with alluvium of lesser specific gravity than the normal crust; and a belt of excessive density to the south of the geosynclinal trough. This belt exerts a strong gravitative influence equivalent to a mountain ridge and has become known as the Hidden Range.

To those who note only the discrepancies between the facts of observation and the Hayford hypothesis, the whole theory of isostasy may appear shaken. Hobbs goes so far as to state: "Applied in the region where

[33] H. H. Hayden, Notes on the relationship of the Himalaya to the Indo-Gangetic plain and the Indian peninsula, Records Geol. Survey India, 43, pt. 2, 138-167, 1913.

it is most crucially tested, the Hayford hypothesis thus receives less support in the facts than does the doctrine of non-compensation."[34]

Instead of analyzing the subject with a microscope, let us stand off from it far enough to get a perspective view of the whole problem, comparing the discrepancies with the agreements, and it will be found that the evidence for the existence of isostasy is as striking and conclusive for India as for the United States. The following table has been made up by the writer from the detailed results given by Crosthwait.

*Mean deflections and residuals for India.*

| A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| Group. | Region. | Number of stations. | Mean topographic deflection in seconds. | Mean deflection for topography compensated at depth of 113·7 km. | Mean observed deflection. | Mean residual for hypothesis of no isostasy Col. F.—Col. D. | Mean residual for compensation at depth 113·7 km. Col. F.—Col. E. | Ratio of residuals. Col. H. divided by Col. G. | Ratio of residuals to topographic deflections. Col. H. divided by Col. D. |
| 1 | Himalayan foothills | 6 | −77·5 | −15·2 | −30·7 | +46·8 | −15·5 | 0·33 | 0·20 |
| 2 | Plains at foot of Himalaya | 4 | −70·7 | − 6·2 | − 8·5 | +62·2 | − 2·3 | 0·04 | 0·03 |
| 3 | Northeast India | 10 | −44·7 | − 0·2 | + 7·7 | +52·4 | + 7·9 | 0·15 | 0·18 |
| 4 | Central India | 6 | −30·7 | + 0·3 | + 5·5 | +36·2 | + 5·2 | 0·14 | 0·17 |
| 5 | Northwest India | 21 | −35·0 | − 0·5 | + 3·9 | +38·9 | + 4·4 | 0·11 | 0·13 |
| 7 | Western India | 23 | −34·7 | − 0·4 | − 3·0 | +31·7 | − 2·6 | 0·08 | 0·07 |
| 8 | Eastern India | 17 | −48·1 | − 2·5 | − 4·6 | +43 5 | − 2·1 | 0·05 | 0·04 |
| 9 | Southern India | 14 | −40·1 | − 0·8 | + 0·4 | +40·5 | + 1·2 | 0·03 | 0·03 |
| All | United States | 733 | 30·4 | ..... | ..... | ..... | 2·9 | ... | 0·10 |
| 5 | Wisconsin-Michigan | 52 | 9·0 | ..... | ..... | ..... | 3·7 | ... | 0·42 |
| 10 | Southern California coast | 57 | 65·4 | ..... | ..... | ..... | 3·9 | ... | 0·06 |

[34] W. H. Hobbs, op. cit., p. 702.

It is seen that for India the deflections computed from the topography alone, as listed in column D, give a systematic attraction of the plumb-line to the north. This is due to the great elevations of the Himalaya Mountains and the Tibetan plateau to the north and to the deep ocean basins to the south. The plateau of India is thus the middle one of three great steps in the earth's surface. This is why the topographic deflections for most of the regions are much larger than for the United States. The computations on the hypothesis of complete compensation of the topography at a depth of 113·7 kilometers are given in column E and are seen to reduce the topographic deflections to very small quantities for all regions except those adjacent to the Himalaya. This is of course no proof of isostasy unless the computed deflections correspond to the observed deflections. The differences between the observed deflections, shown in column F, and the topographic deflections are given in column G. They are a measure of the error of the hypothesis of no isostasy on the assumption that the Bessel-Clarke spheroid is correct. This measure of the error of this hypothesis is not directly comparable with the residuals for the United States of solution B, the hypothesis of no isostasy, for the reason that in solution B such values of the radius and polar flattening were taken as made the sum of the squares of the residuals smallest and these constants were appreciably different from those of the Bessel-Clarke spheroid. The terrestrial dimensions adopted by Hayford for the hypothesis of isostasy are also different from those of the Bessel-Clarke spheroid, but probably not enough to affect the comparison of isostasy in the two countries.

Column H shows the discrepancy between the observed deflections and the deflections for topography fully compensated at a depth of 113·7 kilometers. Columns G and H are therefore the residuals given by the two hypotheses. Their ratio, as given in column I, measures their relative probabilities. Although the residuals for both hypotheses are large for the Himalayan foothills, it is seen that the mean for the Hayford hypothesis is only one-third of the mean for no isostasy. The average of the means for the other groups shows that the particular hypothesis of isostasy which is used gives residuals less than a tenth as large as the hypothesis of no isostasy.

For the United States, Hayford used, as a test of his hypothesis, the ratio of mean residuals to the mean topographic deflections.[35] This is the ratio of column H divided by column D. Such a test is in reality invalid for reasons which have been discussed previously; but for purposes of comparison with the United States this ratio is also given in the present table for India as column J. The values selected from the United States are for the whole of the United States and for groups 5 and 10 of the fourteen regions which compose the whole.

Group 5 embraces the Lake Superior region and is that for which the residuals bear the highest ratio to the topographic deflections for any region in the United States, making the poorest showing for the special hypothesis. Group 10, in southern California, is the region showing the largest topographic deflections and largest residuals of any region in the United States.

It is seen that for India, exclusive of the Himalayas and the Gangetic trough at their feet, the Hayford hypothesis of isostasy gives as satisfactory results, as shown in column J, as for the United States. This agrees with the conclusions of Bowie as based on gravity determinations.[36]

The statement of Crosthwait that "speaking generally it would appear that isostatic conditions are much more nearly realized in America than in India" is not true for India as a whole. The residuals of groups in India removed from the Himalaya are as small as those of groups of equal size in the United States. Crosthwait's comparison was poorly based in that he compared individual groups in India with the four quarters of the United States. Furthermore, he did not separate in his statement the problem of the Himalayas and the Indo-Gangetic trough from that of the plateau of India. Instead, then, of using the large residuals adjacent to the Himalayas as an argument that isostasy does not apply well to India, the proper attitude is to ask what it means. Fortunately Oldham has investigated this problem and has gone far toward solving it in a recent comprehensive research.[37]

Oldham simplified the topography by determining the

[35] J. F. Hayford, Supplementary investigation, p. 59, 1910.

[36] William Bowie, Isostasy in India, Jour. Wash. Academy Sciences, 4, 245-249, 1914.

[37] R. D. Oldham, The structure of the Himalayas, and of the Gangetic plain, as elucidated by geodetic observations in India, Memoirs Geol. Survey India, 42, pt. 2, 1917.

form of a series of blocks which should have the same mass and gravitative effect as the Tibetan plateau, the Himalaya mountains, and the Siwalik foothills. He then constructed tables showing their effect and that of various forms of compensation upon the deflection of the vertical at various distances. Next he chose several forms of the Gangetic alluvial trough filled with alluvium of density 2·2 and computed the gravitative effects of these, both compensated and uncompensated, upon the vertical at various distances. The effects on the intensity of gravity were also ascertained. The variety of tests formed a series and avoided the arbitrary selection of a special hypothesis. Using these tables, there were found to be certain limits which would give computed results agreeing closely with those observed. To obtain this agreement it was necessary to introduce the hypothesis of regional compensation, implying the existence of a strong crust lying on a denser and weaker substratum. Oldham states this conclusion as follows:

"We can now summarise the separate conclusions which have been reached, and attain an understanding of the general distribution of the compensation of the Himalayas. In the central part of the range the compensation is in excess of the load which it is supposed to support; in the outer Himalayas, at a distance of 30 to 40 miles in from the edge of the hills, it is in very considerable defect; and somewhere between these two regions must come a tract where the compensation and topography are in adjustment with each other, where, in other words, the anomaly of gravity should be zero, proper allowance being made for the effect of compensation. Towards the outer edge of the hills the defect of compensation diminishes and the anomaly must ultimately become zero once more.

"A variation of this kind in the adjustment between topography and compensation, or between load and support, is with difficulty intelligible, except on the supposition of a support of the range by flotation, and certainly finds easiest expression in terms of that hypothesis. In the centre of the range the downward protuberance of the crust is over-developed and there is an excess of buoyancy, tending to make the range rise; the excess of load in the outer hills would then be an indication that such rise has taken place, carrying with it the outer hills, till the load thrown on the central tract became large enough to check the further uplift and leave the main range at a lower elevation than that which would result from the protuberance beneath it, while, on the flank of this central tract, the outer hills are upraised beyond the height which they would attain by the effect of the support immediately below them."

"It will be seen that this development of the consequences

which would result from the hypothesis of a floating crust, supported on a denser, plastic, but not necessarily liquid, substratum, is in close accordance with the larger features of the structure of the country south of the Himalayas. It provides for the trough, for the elevation of part of the earlier deposits formed from the waste of the hills on the north of this trough, and for a gradual extension, by progressive regular subsidence, to the southwards, as the range itself grew in magnitude; it provides also for that belt of positive anomaly of gravity, traversing the Peninsula, with its concomitant effect on the plumb-line; and it may be added that the strength of the crust, required to produce these effects, is much the same as that deduced by Prof. Barrell from the geodetic work in North America. This agreement, between the results of conclusions drawn from observation and those obtained by deduction, lends considerable support to the hypothesis on which the deductions were based, but it must be confessed that the Himalayas are the only range where anything like this agreement has been found, yet even this may rather strengthen than weaken the support, for it may well result from the magnitude of the range, which is not attained by any other mountains of the world. It is conceivable that only in the mountain system, of which the Himalayas form the culminating member, do the gravitational stresses set up by the processes of mountain formation reach a magnitude which enables them to dominate all other influences, and to produce a simplicity and magnitude of structure, obscured in other cases by the action of other influences and resistances, which become more prominent with the decrease in the magnitude of the gravitational stresses.''[38]

The outer Himalayas thus possess a partly uncompensated *excess* of mass and tend to press down the crust. The Gangetic trough, with a depth on the north of 15,000 to 20,000 feet, has an uncompensated *deficiency* of mass. It is depressed by the weight of the overthrust mountains to the north. The Hidden Range to the south of the trough has likewise an excess of mass. These relations account for the large residuals and the change in sign of the deflections on the two sides of the alluvial basin.

In this great modern geosyncline there is thus geodetic evidence that the weight of sediment is far from being the cause of depression. The depression is due to the weight of the adjacent mountains and, so far as the alluvial filling is concerned, its deficiency of mass tends toward uplift and erosion, not depression and further sedimentation.

Yale University,
New Haven, Conn.

[38] R. D. Oldham, op. cit. pp. 114-115, 128-129.

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## Art. XXII.—*Pre-Cambrian and Carboniferous Algal Deposits;* by W. H. Twenhofel.

Not very long ago the view generally prevailed that, except for their contributions to the coal series, plants played a very insignificant part in the building of sedimentary rocks. The average textbook in geology still gives the general impression that calcareous deposits indicate accumulations of coral and shell and essentially nothing is said relating to the contributions of the plants. So strong was the view intrenched that calcareous deposits are of animal origin, that plant structures, as *Spongiostroma, Sphærocodium, Cryptozoon* and others, were classed with the animals.

The work of recent years is leading to the conception that as rock-builders the plants—chiefly the algæ—are of prime importance. This work must ultimately compel a restatement of the agents of limestone formation and a general re-evaluation of the quantitative importance of the several agents concerned. At one extreme, this work relates to some of the oldest of rocks and, at the other, to sediments now accumulating on the ocean floor. In addition, considerable detailed work has been done in intermediate portions of the geologic column, particularly the Carboniferous of Great Britain and the Silurian and Ordovician of the Scandinavian countries.[1]

Walcott's explorations[2] of the Pre-Cambrian strata together with contributions relating to the same rock from other students have shown the great part that algæ

[1] An excellent review of the algal deposits of the geological column is given by Garwood, E. J.: Geol. Mag., N. S., Dec. V, vol. 6, pp. 440-446, 490-498, 545-553, 1913.

[2] Walcott, C. D.: Pre-Cambrian Algal Flora, Smithsonian Misc. Coll., vol. 64, No. 2, 1914.

have taken in the building of some divisions of the Pre-Cambrian limestones. The data have been chiefly derived from the Rocky Mountain region, but that is probably due to the fact that paleontologic studies of Pre-Cambrian rocks have been to a very great extent confined to that region. There is little doubt that algal deposits will ultimately be found to be equally abundant in all other Pre-Cambrian terranes during the formation of which conditions obtained which were adapted to the presence of algæ. Doctor C. K. Leith's photographs of some of the rocks to the east of Hudson Bay[3] show that algal deposits are abundant in some of the limestones of that region and in the paper by Doctor Grout and in this paper it will be shown that they are also extremely abundant in some Pre-Cambrian terranes of the Lake Superior country.

The contributions of the algæ to modern deposits are of great importance and in the building of the "coral reefs" they appear to have played a role that from a quantitative point of view is equal to that of any other organism. At Funafuti the relative importance of the organisms forming the reef were *Lithothamnium, Halimeda,* Foraminifera, and lastly the corals,[4] while about the Murray Island coral reef (north end of the Great Barrier reef) at 200 feet from the shore the algæ constitute 42·5% of the sediments and the corals 34·6%. At 1600 feet from the shore the algæ make 32·6% of the sediments and the corals 41·9%.[5]

In the Carboniferous rocks of Great Britain, Professor E. J. Garwood has found algal deposits in abundance in some horizons and he personally suggested to the writer that such would likely be found to be true for American Carboniferous strata.[6] In the highest Ordovician formation (Stage 5) of the Kristiania region of Norway, entire beds of limestone are composed of algal remains and in Gotland the *Spongiostroma* and *Sphaerocodium* marls and limestones receive their names from the abundance of algal material.[7]

[3] Recently described by Moore, J. C.: Jour. Geol., vol. 26, pp. 412-413, 1918.

[4] Howe, M. A.: The Building of "Coral Reefs"; Science, vol. 35, pp. 837-842, 1912.

[5] Vaughan, T. W., and Goldman, M. I.: Papers from the Dept. Marine Biology of the Carnegie Institution of Washington, vol. 9, pp. 255-258, 1918.

[6] Garwood, E. J.: Geol. Mag., Dec. VI, vol. 1, pp. 265-271, 1914.

[7] Munthe, H.: Guide Book, No. 19, XIth Internation. Geol. Cong., 1910.

These facts relating to algal deposits are of immense importance in connection with the formation of limestone and they become of greater significance when it is remembered that many marine algæ thrive almost as well in cold waters as in warm and that in some cold waters their deposits constitute a large percentage of the sediments.

It would seem that in the Pre-Cambrian periods the algæ would have been likely to have had a greater absolute importance than in later times. Before the advent of the manifold variety of bottom animal life, they had the entire submerged area at their disposal where they dwelt undisturbed by competitors or enemies. When the bottom animals appeared in abundance the algæ furnished food for many of them and had to compete with them for space and this must have brought about some decrease in their absolute and certainly in their relative importance.

In this paper are described the occurrence of algal deposits in the Lower Huronian of Michigan and in the Pennsylvanian and Permian of Kansas and Oklahoma. For the opportunity of studying the field distribution of the Kansas and Oklahoma occurrences the writer is indebted to Mr. B. E. LaDow of Fredonia, Kansas; for the opportunity of seeing the Huronian occurrence he is indebted to Doctor C. K. Leith.

### *Method of Origin of Algal Deposits of the Type Considered.*

The algal deposits considered in this paper are of the incrusting or laminated type and one of them is quite similar to the "water biscuits" of modern lakes. These are thought to develop as a consequence of the absorption of the carbon dioxide in the water and the release of oxygen by the plant to the water.[8] These changes in the gaseous content of the water surrounding the plant lessen the capacity of the water to hold the dissolved calcium carbonate and this is precipitated about the bases of the algæ and upon their thalli. The precipitated material has a laminated structure which probably results from variations in the rate of precipitation and interruptions thereof. The process is not one wherein the lime carbonate enters into the tissues of the plant and hence the precipitated material may develop little or no internal

[8] Davis, C. A.: Geol. Surv. Mich., vol. 8, pt. 3, p. 69, 1903.

structure which resembles the structure of the plant. It is possible that the filaments and thalli of the algæ may leave molds within the precipitated material.

### *Terminology and Principle of Classification.*

The terms employed for the lime carbonate structures which are formed in the manner outlined above are not uniform. Garwood, Howe and others use the term thallus, but that term had better be limited to its original significance. It is true that in some cases the precipitated lime carbonate may have the same general shape as the thalli, but even in those cases there is considerable doubt as to the propriety of calling the precipitated material by the same name as the leaf-like structures of the plant. Some writers have called these structures algæ, but to so term them has about the same application as calling a worm boring a worm. Howe and others use the term thallium with a suitable prefix for certain parts of these structures, as hypothallium, perithallium, etc. While appropriate, that term, however, has already been used as the name of an element. As a suitable name for these algal structures appears to be lacking and as one is certainly needed, the writer proposes the word, *cœnoplase,* from *koinos,* common, and *plasis,* formation. This term is used in the present article.

A cœnoplase from the very nature of its origin may, or may not, show anything of the structure and characteristics of the plants which are responsible for its development and algæ giving rise to cœnoplases quite similar in shape may be widely different in appearance and general make-up. On the other hand it appears to be reasonable to believe that algæ belonging to the same genus would develop cœnoplases of so similar a form and structure that little distinction could be made between the deposits of different species and deposits of closely related genera might also be apt to be quite similar in general appearance. If these assumptions be correct, it follows that small constant differences in the shape, size and structure of cœnoplases are to be given a far greater importance than would be the case were one dealing with essential structures of animals and plants. It is on this basis that the Carboniferous algæ described in this paper are referred to different genera.

*Algal Deposits of the Kona Dolomite.*

The Kona dolomite is a Lower Huronian formation of the Marquette region of northern Michigan. It consists of "a cherty dolomite interstratified with layers of slate, graywacke, and quartzite, with all gradations between the various mechanical sediments and between these and the pure dolomites. The texture varies from quite fine to very coarse and the color from a white to a dark-brown. The dolomite does not appear to constitute more than a half of the formation and the beds vary from a few inches to many feet."[9] The thickness varies from 200 to 700 feet.[10]

In the spring of 1917 the writer had the good fortune to accompany Doctor C. K. Leith and his party of students on the field trip which constitutes a part of the course in "Lake Superior Geology." Among other things geological, the Kona dolomite was studied in one of its best exposures, this being situated on the shore of Lake Superior just south of the city of Marquette.

The most striking feature of the dolomite in this exposure is the abundance and large size of the algal cœnoplases which compose it. So far as could be observed, the entire mass of dolomite developed through the progressive plastering of one layer of algal material upon another, the only material of other origin which was observed consisting of insignificant streaks of silt between the algal masses. With the assistance of Doctor W. O. Hotchkiss a group of colonies having a continuous growth from base to summit was measured. It was found to have a thickness of 22 feet with neither base nor summit exposed and a width of 55 feet with neither end shown. This is the extent of the exposure and the actual dimensions must be much greater. Since the dimensions given are of "coral reef" proportions, it can not be doubted that reefs of algæ existed in the Lower Huronian sea of this region.

So far as the writer has been able to learn, the algal growths are not coextensive with the distribution of the Kona dolomite, this being the only place where they have been observed in the formation.[11] In Huronian times

[9] Van Hise, Bayley and Smith: U. S. Geol. Surv., Mon. 28, p. 244, 1897.
[10] Van Hise and Leith: U. S. Geol. Surv., Mon. 52, p. 258, 1911.
[11] Hotchkiss, W. O.: Personal communication.

algæ were probably related to light in their distribution just as they are to-day, and this factor would have confined them to the shallows about the margins of the lands which they would have reefed just as the corals and algæ reef tropical lands at the present time. Places where clastic sediments were being deposited in the Huronian

FIG. 1.

FIG. 1. *Collenia kona* n. sp. Cross section of a single colony, Kona dolomite, Marquette, Mich. Photograph by Dr. W. O. Hotchkiss.

sea or were being transported along the shore would have been free from algæ. Their places of abundant growth would have been found in clear and shallow waters. This fact of distribution probably explains their general absence from this dolomite formation. It is quite likely, however, that some of the dolomite which shows no evidence of algal origin may have so originated; but have lost all traces of its origin in the process of recrystallization.

The character of the water can hardly be determined from the algæ. These organisms at the present time thrive in cold as well as in warm waters, illustrated by the fact that in the cold waters of some localities of northern Newfoundland *Lithothamnium* covers everything in the shallows, and about the "coral reefs" it is one of the most abundant organisms precipitating lime carbonate. The algæ do not even prove that the waters were salty,

FIG. 2.

FIG. 2. *Collenia kona* n. sp. Cross section of two colonies, Kona dolomite, Marquette, Mich. The hammer is 18 inches long. Photograph by Dr. W. O. Hotchkiss.

as lime-precipitating algæ thrive in both fresh and salt waters, but the tremendous growth of the Kona algæ suggest marine conditions.

The upper surface of the Kona reef was irregular from the presence of elevations which are dome-shaped in cross section. Some of these elevations appear to have been as

great as 10 feet across. Small secondary domes are superimposed upon the larger ones. Most of the domes are from 6 inches to 2 feet in diameter. The relief arising from these elevations appears to have been about a foot.

Each dome seems to have represented a more or less separate colony which was separated from neighboring elevations by V-shaped depressions in the apices of which small quantities of silt collected and as the reef grew upward both the separating hollows and the domes appear to have held about the same relative positions. As a consequence, each dome continues downward into the reef as a cylindrical structure which in some cases terminates at the base in a round-apexed cone. Some of these cylindrical structures attained lengths of 7 to 10 feet.

The structure of the reef material is laminated, growth having taken place through the deposition of laminæ over the external surface of the dome-shaped masses. The structure and general features of the cœnoplases appear to be similar to those occurring in the genus *Collenia* Walcott of which genus this is considered a new species.

*Collenia kona* new species.

Growths of large size; dome-shaped on the upper surface; diameters varying, but mostly 2 feet or less; structure consisting of superimposed laminæ parallel to the upper surface and hence convex upward. The laminæ vary in thickness from one to several millimeters. They are wrinkled and in cross section appear as small anticlines and synclines of 3 to 5 millimeters amplitude. A part of this wrinkling may have arisen from the pressures to which the rock has been subjected, but probably very little of it did so arise. A colony probably began as an incrustation over some other substance; but after covering the bottom, more rapid growth in one place than in another gave rise to domal shapes which by growth upward in the same position led to cylindrical structures. The upper surface of the algal reef appears to have had a somewhat large-featured botryoidal aspect.

Horizon and locality. Kona dolomite, Lower Huronian, near Marquette, Michigan.

The holotype and paratype are in the collections of the Department of Geology, University of Wisconsin.

*Algal Deposits of the Bad River and Ironwood Formations.*

The Bad River dolomite (Lower Huronian) and the Ironwood formation (Upper Huronian) of the Gogebic Range contain algal deposits. These from the latter formation are composed of chert and form a bed which is 5 to 6 inches thick.[12] The structure is laminated with the conspicuous divisions between laminæ from a half to a millimeter apart. The laminæ and the upper surface are domed, with the domes not more than an inch across. The material which the writer had for examination is hardly sufficient for detailed description. The writer has not seen the algal material from the Bad River dolomite. According to Doctor Hotchkiss they do not form colonies, but occur as isolated individuals in the dolomite. They are of domed shape and vary from 3 to 6 inches in diameter.

*Pennsylvanian and Permian Algal Deposits.*

In southeastern Cowley County, Kansas, the beds belonging to the Crouse limestone member of the Permian system contain an abundance of algal cœnoplases of the "water biscuit" type. A section illustrating the occurrence is as follows:

25. Wreford limestone member (summit of the section).
24. Largely concealed, partly red gritty shale 40 to 50 feet.
23. Brown, medium-grained sandstone ............3 feet.
22. Mostly concealed, some red shale and brown sandstone... 9 feet.
21. Gray semi-crystalline limestone .........4 to 5 inches.
20. Mostly concealed, some shale and brown sandstone ..... 9 feet.
19. Wave ripple-marked, gray weathering semi-crystalline limestone; rarely seen in position, generally occurring as slabs on slopes ...................................12 inches.
18. Mostly concealed, but some shale and thin limestone..... 11 feet.
17. Two beds of fine-grained gray limestone, weathers full of round vertical holes, rings when struck .......16 to 18 inches.
16. One bed of gray, semi-crystalline limestone, poorly fossiliferous, weathers full of round vertical holes ......12 inches.
15. One bed of gray limestone filled with *Fusulina* 6 inches.
14. Thin-bedded limestone, bedding poorly defined, contains many *Fusulina* and other fossils, many being thinly incrusted with calcareous material which is probably of algal origin...... 15 inches.

[12] Hotchkiss, W. O.: personal communication.

13. Nodular, gray shaly limestone with numerous fragments of fossils. Bedding irregular. Contains many cœnoplases of *Lithothamnium*-like algæ ....................2 feet 5 inches.

12. Gray nodular limestone, weathers yellow. Very fossiliferous, containing *Derbya, Bellerophon, Productus,* bryozoa, cœnoplases of *Lithothamnium*-like algæ and other fossils[13]...... 8 inches.

11. Concealed, probably shale ..................15 feet.

10. One bed of thin, fine-grained gray limestone............ 4 to 6 inches.

9. Concealed ..................................6·5 feet.

8. One bed of gray limestone, generally seen as slabs on the slopes ...................................8 to 10 inches.

7. Concealed, supposedly shale ..................16 feet.

6. One bed of gray limestone ............12 to 14 inches.

5. Gray limestone with poorly defined bedding .....3 feet.

4. Mostly concealed, presumably shale, but contains a little limestone .........................................15 feet.

3. Brittle gray limestone, irregularly bedded ......4 feet.

2. Gray limestone, irregularly bedded and full of *Fusulina* 1 foot.

1. Shaly, nodular gray limestone ..........2 feet exposed.

The algal deposits were not seen elsewhere than in the zones in which they have been noted and their occurrence may be coextensive with the distribution of these zones, but because of the weakness of the rocks of which they are composed, exposures are rather uncommon so that the algal material was not seen in very many places.

Only a single species of alga appears to be represented, and it apparently belongs to an undescribed genus. The incrustations about the fossils of zone 14 probably belong to the same species.

*Ottonosia* new genus.

Irregularly shaped cœnoplases which begin as incrustations around other substances and increase in size through the deposition of material over and around that already deposited. The diameters vary up to about 85 millimeters. Most of the cœnoplases are biscuit-shaped; a few are spherical. In small specimens the shapes appear to have been determined by the shapes of the nuclei. One specimen which has the convex valve of a *Derbya* for a nucleus still retains that shape, the shell being covered with about one eighth inch thickness of

[13] Zones 12 to 17 constitute the Crouse limestone.

algal material. The exteriors are irregular through the presence of little cylindrical-sided domes and their separating depressions. The elevations arise from one another and there is great irregularity in shapes, sizes and degrees of divergence.

The interior structure consists of very thin and closely placed concentric laminæ and these repeat the irregularities of the exteriors. A depression on the surface is apt to be continued into the interior by small lines or streaks of fine sand and mud. These streaks are interpreted as arising from small quantities of mud and sand becoming

FIG. 3.

FIG. 3. *Ottonosia laminata* n. sp. X 2. Microphotograph of section of the holotype. The white streak across the middle is a cross section of the shell nucleus. Crouse limestone, near Otto, Kans.

lodged in the depressions between the domes. Some tube-like structures which penetrate portions of the interior may have been produced by the boring of annelids or mollusks, or they may be molds of the thalli or algæ. These are also filled with fine sand and mud. The laminæ vary in thickness; at one place eight were distinguished in a thickness of five millimeters; at another place only five laminæ are present in the same thickness.

*Relationships.*—In general appearance the cœnoplases of this genus resemble those of *Sphaerocodium* Rothpletz from the Silurian of Gotland, but differ in the general absence of a spherical form and in the nature of the irregularities of the surface. Internally, *Sphaerocodium* is said to have concentric tubes around the nucleus; such

are not present in this form. It differs from *Girvanella* Nicholson and Etheridge Jun. in the same respect. The internal structure of the genus *Ortonella* Garwood from the Lower Carboniferous of England is characterized by decided dichotomous, radial tubes, none of which has been observed in this genus. It differs from *Solenopora* Dybowski in the same way. Except for the "water biscuits" of modern lakes and *Lithothamnium,* there are no other genera with which it may be compared and its resemblance to neither of these is very close.

FIG. 4.

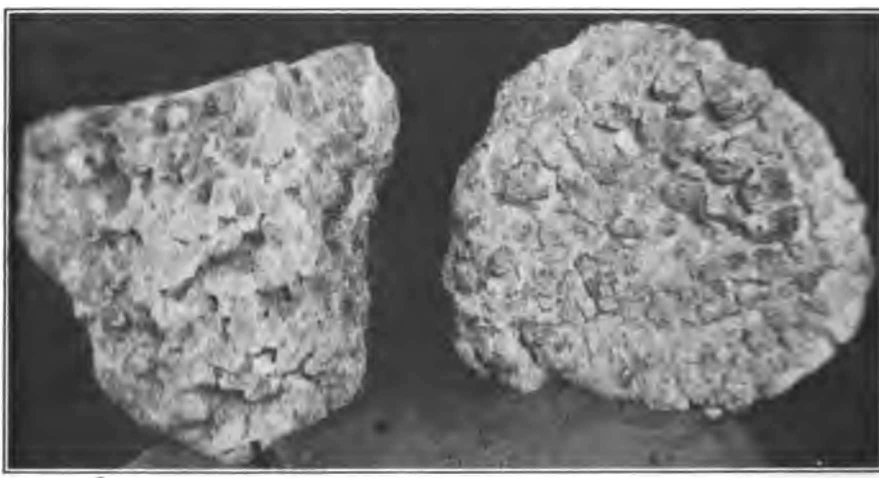


FIG. 4. *Ottonosia laminata* n. sp. Natural size. The thin section was made from the specimen on the left. The specimen on the right shows the irregularities of the surface. Crouse limestone, near Otto, Kans.

The generic name is based on the name of the village near which the type species occurs in abundance. The genotype is *Ottonosia laminata* n. sp.

*Ottonosia laminata* new species.

FIGS. 3 and 4.

The characters of the species are given in the generic description. The specific name is derived from the laminated structure of the interior.

Horizon and locality. Occurs in considerable abundance in the Crouse limestone member of the Permian in northern Osage County, Oklahoma, and Cowley County,

Kansas. It is particularly abundant just north of the little village of Otto, Kansas. It also occurs in the Florena shale at Grand Summit, Kansas.

The holotypes and paratypes are in the collections of the writer.

*Osagia* new genus.

The Foraker limestone (Pennsylvanian) of southeastern Cowley County, Kansas and Osage County, Oklahoma, particularly in some of the Ekler Canyon exposures, in some horizons contains an abundance of

Fig. 5.

Fig. 5. *Osagia incrustata* n. sp. X 5. Camera lucida drawing of thin section. The light colored areas within the dark represent nuclei. Circular dark areas are cut perpendicular to the long diameters of the cœnoplases. From type locality, Ekler Canyon, about 7 miles southwest of Cedarvale, Kans.

algal cœnoplases of small size. The shapes are such that on casual examination they are apt to be mistaken for *Fusulina*. It is possible that these cœnoplases may represent a new species of *Ottonosia;* but as none attains a large size and the concentric laminæ do not appear to be wrinkled, they are considered the type of a new genus. This view is strengthened by the tendency to develop a fusiform shape. Thin beds of limestone are almost wholly composed of these algal remains.

When first discovered it was thought that possibly these structures might have developed through the chemical inorganic precipitation of material around nuclei. This led to a search for oolite and pisolite. None has been found and it is quite certain that they do not occur in association. This fact, considered in connection with the

additional fact that no matter what the nucleus may be, a fusiform shape tends to be developed, makes it quite certain that they are of organic origin.

The cœnoplases are about the shape and size of Fusulina, but are generally a little larger and more robust. Each has a small fragment of rock or shell for a nucleus. In one observed instance the nucleus consists of a small pellet of fine-grained sand and mud. It is probable that anything would serve. Dimensions range to a length of about 7 millimeters and a thickness of about 4 millimeters. The exteriors are imbedded in the rock, but they appear to be smooth or only slightly irregular. The interior structure consists of thin concentric laminæ of which there are from 4 to 6 to a millimeter. No radial structures of any kind were observed.

All of the specimens are so discolored by limonite that it was not possible to photograph them in thin section. The greater part of the limonite occurs within the cœnoplases, the surrounding matrix generally being composed of quite clear calcite. It is considered quite certain that the limonite was precipitated in the cœnoplase at the time it was formed and that there is some genetic connection between the limonite and the algæ which were responsible for the cœnoplases.

*Relationships.*—In method of development the cœnoplase of this genus resembles all others of concentric laminated structure. The small size, the general absence of a wrinkled exterior and the tendency to assume a fusiform shape are rather marked features of difference.

The generic name is taken from Osage County, Oklahoma, on the northern border of which the cœnoplases occur in abundance. The genotype is *Osagia incrustata* n. sp.

*Osagia incrustata* new species.

Fig. 5.

The generic description gives the characters of the species, the specific name calls attention to the incrusting habit.

Horizon and locality. Foraker limestone, Pennsylvanian, Ekler Canyon, southern Cowley County, Kansas and northern Osage County, Oklahoma.

The holotype and the paratypes are in the collection of the writer.

University of Wisconsin,
Madison, Wis.

ART. XXIII.—*On Ferrazite? A new associate of the Diamond;* by T. H. LEE and LUIZ FLORES DE MORAES.

Among the voluminous researches of the late Eugen Hussak some of the most interesting are his patient investigations of the dense minerals found in diamond-washing, which extended over a number of years.

Apart from the great number of minerals studied and determined by him and made known to the scientific world by the publication of his posthumous work "Os satellites do Diamante," edited by our colleague Dr. Jorge Belmiro de Araujo Ferraz, considerable and valuable material exists in the Hussak mineral collection, acquired and conserved by the Brazilian Geological Service, in which our colleague encountered and handed to us for analysis a number of "favas"[1] with Hussak's own label "Pb-Al hydrophost. D.-3.095.Neu!"

From the results of a preliminary analysis it appeared that, in addition to lead, barium was also present, which led us to carry out a complete analysis, leading to the following results:—

| | |
|---|---|
| Combined water | 14·20 |
| Lead oxide | 45·63 |
| Barium oxide | 8·87 |
| Lime | traces |
| Alumina | 3·48 |
| Phosphoric anhydride | 26·24 |
| Silica | 2·44 |
| | 100·86 |

Considering the silica to be present as kaolinite, and the excess of alumina over and above that required by the silica to be present as wavellite, the composition of the "favas" should be represented as follows:—

| | New Mineral | Kaolinite | Wavellite |
|---|---|---|---|
| Combined water | 12·48 | 0·71 | 1·01 |
| Lead oxide | 45·63 | — | — |
| Barium oxide | 8·87 | — | — |
| Alumina | — | 2·05 | 1·43 |
| Phosphoric anhydride | 24·92 | — | 1·32 |
| Silica | — | 2·44 | — |

[1] *Favas:* English equivalent "Beans." This name is applied to certain dense rounded flattish pebbles found with the dense residues from gravel in the diamond-washers batéas.

Calculating anew the composition of the new mineral on a centesimal basis, we have:—

| | | Molecular ratios |
|---|---|---|
| Combined water .......... | 13·58 | 0·7544 |
| Lead oxide .............. | 49·65 | 0·2227 |
| Barium oxide ............ | 9·65 | 0·0631 |
| Phosphoric anhydride ..... | 27·12 | 0·1910 |
| | 100·00 | |

Recalculating these molecular ratios on a basis of $P_2O_5$ equal to 2, we have:—

| | |
|---|---|
| Combined water .................... | 7·900 |
| Lead and barium oxides ............. | 2·993 |
| Phosphoric anhydride ................ | 2·000 |

or 3 $(Ba,Pb)O.2P_2O_5.8\ H_2O$.

The density of the "favas" varies between 3·0 and 3·3. The color is a dark yellowish-white, resembling that of old ivory. The specimens are discoid in shape, and thin sections show under the microscope a granular structure suggesting that resulting from the evaporation of a colloid substance.

Dana's System of Mineralogy, 6th Ed. with Supplements I and II mentions no such mineral, although it includes all Damour's results, so that we feel justified in claiming novelty for the mineral, and suggest for it the name of *Ferrazite,* in just recognition of Ferraz's valuable work in editing Hussak's posthumous work, and in classifying and rendering available the precious mineral collection left by him.

ART. XXIV.—*The Hackberry Stage of the Upper Devonian of Iowa;* by CARROLL LANE FENTON.

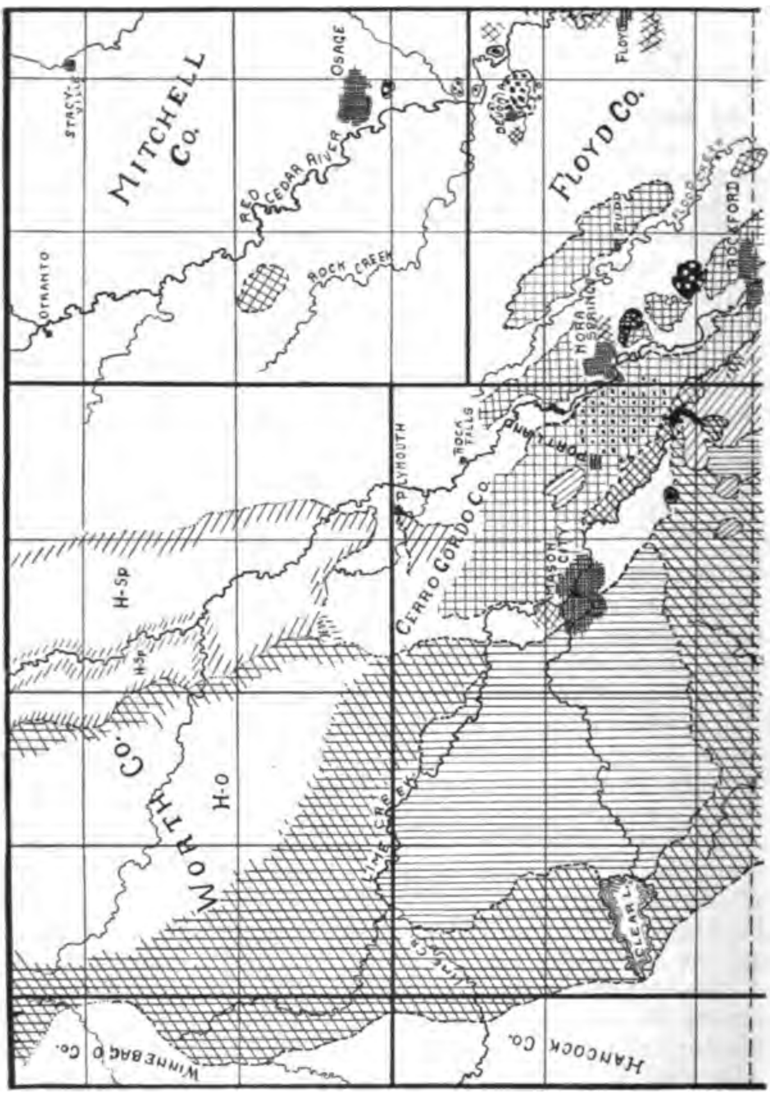
*Introduction.*

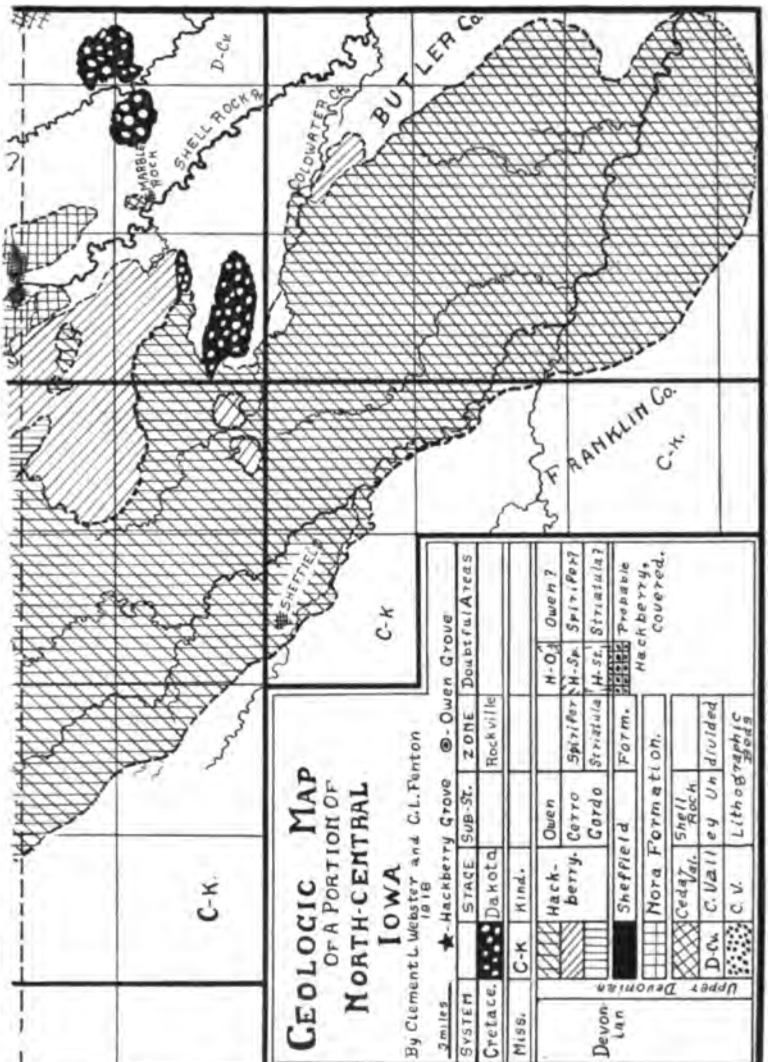
At what is commonly called the Hackberry Grove clay bank, in the northeast quarter of section 35, Portland township, Cerro Gordo County, Iowa, is the type locality of the formation discussed in this paper. On the right bank of Lime Creek at this point is an escarpment some seventy-five feet in height, consisting throughout its entire exposed thickness of two formations: the Hackberry and the Sheffield. These two formations compose what Calvin called the Lime Creek Stage, but aside from the fact that both are members of the Upper Devonian there is very little connection between the two.

A. *The Name "Hackberry."*

In 1889 there appeared, in the *American Naturalist* (vol. **23**, pp. 229-243), a paper by Clement L. Webster entitled "A General Preliminary Description of the Devonian Rocks of Iowa; which constitute a typical section of the Devonian Formation of the Interior Continental Area of North America." In this paper both of the formations exposed at Hackberry Grove were described, that which I have referred to as the Sheffield being placed as Hamilton in age. The "Hackberry Group" as proposed by Webster in this paper "is known to attain a thickness of forty-five feet, and is made up, for the greater part, of a yellowish brown argillaceous, and sometimes arenaceous, shaly limestone"; this formation also is the highest division of the rocks of this age [the Devonian] in the state. Detailed faunal lists are given by Webster, and the formation was described as fully as the condition of the exposures at that time would permit. In later papers Webster gave additional information regarding this formation.

In 1897, Calvin (Iowa Geol. Survey, vol. VII) published a description of what he called the "Lime Creek Stage," which according to his definition includes not only the Hackberry Stage of this paper but also the Sheffield formation. Calvin applied the name "Owen Substage" to those rocks here placed in that division, and





Geologic Map
of a Portion of
North-Central
Iowa
By Clement L. Webster and C. L. Fenton
1918
2 miles
★-Hackberry Grove ⊙-Owen Grove
SYSTEM
STAGE
SUB-ST.
ZONE
Doubtful Areas
Cretace.
Dakota
Rockville
Miss.
C-K
Kind.
Devonian
Upper Devonian
Hack-berry.
Owen
H-O.
Owen?
Cerro Gordo
Spirifer
H-Sp.
Spirifer?
Striatula
H-St.
Striatula?
Sheffield
Form.
Probable Hackberry, covered.
Nora Formation.
Cedar Val.
Shell Rock
D-Cu.
C. Valley Undivided
C. V.
Lithographic Beds
BUTLER Co.
FRANKLIN Co.
SHELL ROCK R.
COLDWATER Cr.
MARBLE ROCK
SHEFFIELD
C-K
C-K.
D-Cu

"Hackberry Sub-stage" to the balance of the Hackberry and the whole of the Sheffield. This division of Calvin's was adopted by the Iowa Survey—of which Calvin was director,—and is at present in more general use than is Webster's classification.

When it is noted that Calvin used "Hackberry" to designate one of the subdivisions of his "Lime Creek Stage" it is naturally questioned whether or not Webster's Hackberry was made to include substantially all of the Owen, and on investigation it will be found that Webster undoubtedly included all of the Devonian rocks overlying the Sheffield formation and underlying the Kinderhook in the district where the Hackberry is known to occur. It is true that he recognized at that time but fifteen feet of the Owen Sub-stage,[1] but there can be no doubt that he recognized at least part of the Owen, and included it in his Hackberry Group. Several of the typical fossils of the Owen were described or mentioned by Webster—among them *Pachyphyllum crassum, P. crassicostatum, Westernia gigantea, W. owensis,* and the very typical species of Acervularia, which Webster at that time considered to be a form of *A. davidsoni.*

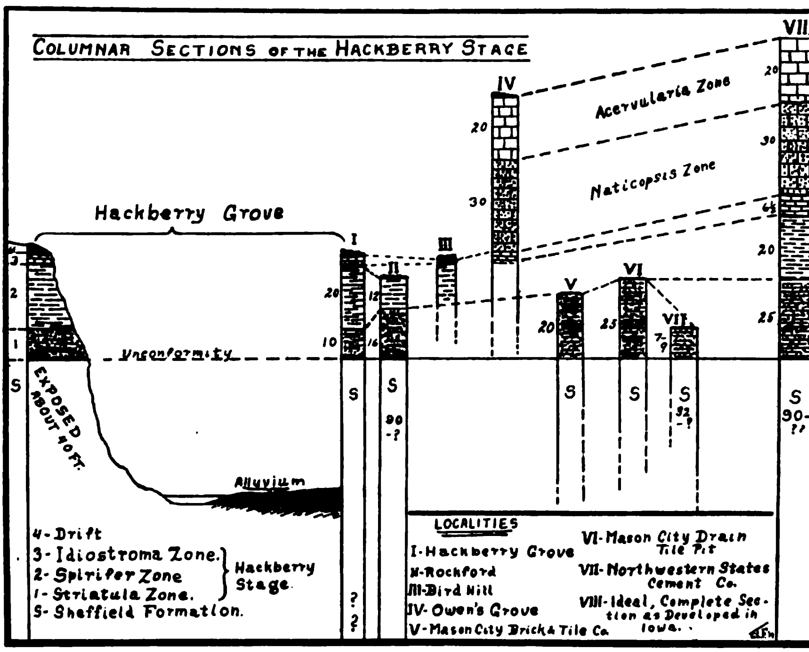
Table showing the divisions of the Hackberry Stage and those formations known to lie below it and above the rocks of undoubted Cedar Valley age.

| Stage | Sub-stage | Zones | Local Faunules |
|---|---|---|---|
| Hackberry | Owen | Acervularia (20 ft.)<br>Naticopsis (30 ft.)<br>Idiostroma (4–6½) | |
| | Cerro Gordo | Spirifer (20 ft.).<br>Striatula (25 ft.) | Stromatoporella<br>Hystrix<br>Gigantea |
| | .......Unconformity.......... | | |
| Questionable | Sheffield Formation (90– ? ft.) | | |
| | .........Unconformity.......... | | |
| Possible Cedar Valley | Nora Formation (25– ? ft.) | | Upper Actinostroma Bed.<br>Parting<br>Lower Actinostroma Bed. |
| | .........Unconformity............ | | |

It is plain that whatever weight there may be in priority of publication is on the side of the term "Hack-

[1] At that time the Striatula Zone was not exposed to more than ten feet.

berry.'' But there is another consideration that seems to be even more important, and that is the way in which Calvin's terminology was evolved. The Iowa Survey's process was this; It took a named formation, added to that formation another (which has no connection with it), and applied an entirely new formation name. It then divided the formation derived by this operation into two sub-stages. To one of these it gave a name that is fitting and suitable—the Owen. For the other it took




the name originally proposed for the entire formation; cut it down on one side to cover less than half of that which it was originally meant to cover; stretched it on the other to include an unrelated formation that it was never intended to include, and thus produced the Hackberry Sub-stage. Errors in thickness, statements that formations that are rich in fossils were unfossiliferous, and similar points I do not take into consideration. They will serve to offset errors in the original description by Webster.

Now that I have again removed the "forty feet of blue, non-fossiliferous shales"—or have tried to do so,—I deal

with a formation that differs in no *essential* from the Hackberry Group of Webster, though it does differ from the Lime Creek of the Iowa Survey. In addition I have the reasons that I have above set forth. I think this explains why the term "Hackberry" is used by me rather than "Lime Creek."

B. *The Stratigraphy and Distribution of the Hackberry.*

At no one point can a satisfactory section of the full Hackberry Stage, as developed in Iowa, be taken. The two type localities—Hackberry Grove, for the entire stage; Owen Grove for the Owen Sub-stage—together with comparisons with points other than these give the complete section. To make reference more satisfactory, the general section of the formation is given here.

*General Section of the Hackberry Stage.*

II.—*Owen Sub-stage.* **Feet**

Acervularia Zone.

Calcareous, light gray limestones, containing ***Pachyphyllum, Alveolites,*** and other corals, in large numbers, an undescribed species of ***Acervularia*** being the most distinctive ........ 20

Naticopsis Zone.

Magnesian shales and limestones, and argillaceous dolomitic limestones, often dark buff or brownish in color. Contains numerous fossils, with gastropods predominating, ***Naticopsis gigantea*** H. & W. the most characteristic species..... 30

Idiostroma Zone.

Buff or buff-brown, heavily bedded limestones. Contain great masses of two species of ***Idiostroma***(?), as well as *S. incrustans* (H. & W.), *S. solidula* (H. & W.), and gastropods ........ 4–6½

I.—*Cerro Gordo Sub-stage.*

Spirifer Zone.

Yellowish, very calcareous shales, shaly clays, and occasional bands of shaly limestone. Weathers partly to clay, and partly to chips or nodules. Extremely fossiliferous ........ 20

Striatula Zone.

Calcareous shales, and shaly limestones, slightly gritty, too much so; contains large amounts of iron pyrite, and near the base often contains large numbers of calcareous concretions. Fossiliferous, but species limited, and usually represented by casts ........ 25

Unconformity.*

(Sheffield Formation underlying)

* There may be some question as to whether this contact is *unconformable* or *disconformable*. Webster considers the former to be more probable.

This gives a maximum of about one hundred feet for the whole Hackberry, although it is very doubtful if it attains this thickness at any one given point. The two lower members are ordinarily of gray-blue color, oxidizing to yellowish.

B, I. *The Striatula Zone.*

At the pits of the Mason City Brick and Tile Company, in the southwest part of Mason City in Cerro Gordo County, the clay-shale of the Sheffield, and the shales and indurated rocks of the lowest zone of the Hackberry, the Striatula zone is well exposed, and the unconformity of the Striatula beds on those of the Sheffield Formation is quite well shown. The thickness of the Sheffield is not definitely known, but there are no indications that it is much less than that of the same beds at Rockford. The Striatula zone attains a maximum thickness of about twenty-five feet, with the lower portion consisting largely of heavy ledges of strongly iron-stained and seemingly dolomitic limestone (Section V). The lower portions of these beds, particularly the indurated layers, contain large numbers of "fucoids" apparently of several species. The most common is a small form of one-fourth to one-half inch diameter, and so far as observed, without branches. It lies along the bedding planes of the rock in large, intermingled, curling masses, and is very characteristic of the lowermost ledges. The other prominent form has a diameter of one to two and one-half inches, branches frequently, and is of considerable length. It is found associated with the first form, but farther up in the beds.

Some three-quarters of a mile to the northwest of the pit noted in Section V are the pits of the Western States Cement Company. Here the total thickness of the Striatula zone is but seven to nine feet; the indurated beds of the various pits operated by the Mason City Brick and Tile Company are represented by a bed not more than four inches in thickness—usually less, but bearing on its surface the characteristic large fucoids of the middle portion of the beds to the south. The dip of these beds is quite strongly to the southwest, but Mr. A. P. Potts, engineer with the Mason City Brick and Tile Company, tells me that the heavy indurated beds have disappeared before one has passed half-way from the pits of that company to those of the cement works. Section VI shows the relative thickness of the beds at this

works. In neither of these pits are there many of the hard calcareous concretions that are so characteristic of the lower portion of the Striatula beds at Rockford, and which are also quite common at Hackberry. The amount of iron seems very considerable; the shale oxidizes to a deep yellow ochre color and pyrite is plentiful.

In the lower portion of the Striatula beds at Mason City there are few fossils other than the fucoids already noted. I have found *Schizophoria striatula* and *Atrypa reticularis* even in the lowest ledges and a little farther up a few fragmentary casts of *Spirifer whitneyi* were collected. As one nears the top of the beds, however, the casts of *A. reticularis, Schizophoria striatula* and *Spirifer whitneyi* become quite numerous, and forms akin to *S. whitneyi gradatus* also occur.

At Rockford the major part of the Striatula zone is smooth-weathering, though rather gritty clay-shale, with a harder zone of about two feet at the base that contains many concretions and much pyrite. Just above this one may find, in fair to good state of preservation, considerable numbers of brachiopods, among them *Leptostrophia canace* (H. & W.), *Douvillina arcuata* (Hall), *Gypidula* n. sp., *Atrypa reticularis* (Linn.) and *Spirifer whitneyi* Hall. Farther up in the beds have been found most of the other species noted in the list of the Striatula zone (C, II*b*).

### B, II. *The Spirifer Zone.*

The most striking, and possibly the most interesting, of the divisions of the Hackberry is that one which Webster and Fenton have designated as the Spirifer zone.[2] It is the third pronounced stratum at Hackberry Grove, where it attains a thickness of about twenty feet. At this point, as at most others, this bed is oxidized to a light yellowish color, and near the top it contains bands of light yellowish limestone with numerous selenite crystals. The selenite is also present in considerable amounts in the same beds at Rockford, in Floyd County.

There are three quite distinct faunules of the Spirifer zone at Hackberry Grove. The lowest is characterized by large numbers of specimens of *Naticopsis gigantea* H. & W., and the allied forms *Floydia concentrica* Web-

[2] Descriptions of some New Brachiopods and Gastropods from the Devonian of Iowa, by Carroll Lane Fenton. American Midland Naturalist, vol. 5, September, 1918.

ster and *F. concentrica multisinuata* Fenton, and may be referred to as the Gigantea faunule. The second is distinguished by the large numbers of finely preserved brachiopods, and in it the genera Atrypa, Schizophoria, Strophonella, Douvillina and Spirifer reach the height of their development in the Hackberry. Corals are plentiful; stromatoporoids are by no means lacking, and at Rockford there are very large numbers of bryozoans in this horizon, yet it is primarily a horizon of brachiopods, and may be referred to as the Hystrix faunule. The third division is not so rich in gastropods nor brachiopods, but is characterized by great numbers of stromatoporoids and corals. Chonophyllum, Charactophyllum, Zaphrentis, Pachyphyllum, Macgeea, Alveolites, Stromatoporella, and Syringostroma are at their height, with the last two genera in particular abundance. This division may be referred to as the Stromatoporella faunule.

At the pits of the Rockford Brick and Tile Company the two lower faunules are developed. The species *Naticopsis gigantea* occurs in the "wrinkled" form of the original description, and *Floydia concentrica* occurs in considerable numbers. The Hystrix faunule is very well developed, with that species and the genus Spirifer as the predominating forms along with *A. reticularis*. At these pits the Stromatoporella faunule is lacking, but to the north and west we again find it in place and characteristically developed. Three miles southwest of Rockford, at what is locally known as Bird Hill, an exposure by the roadside has several features of interest. Here the lower exposed beds are of quite hard shale, evenly stratified, and everywhere crowded with fucoids. There is an interesting parallel with the beds of the Striatula zone at Mason City, for the fucoids of the lower portion of this member are smaller, less inclined to branch, and much more numerous than those of the upper portion of the bed. These latter branch frequently, have a thickness of two to as much as five inches and an apparent length, at times, of three to four feet. Above these fucoid beds are the shaly clays containing the Hystrix faunule, which is here very rich in both brachiopods and bryozoa.

A quarter of a mile to the west of Bird Hill, and still on the same ridge, is a cut that shows beds containing

the Hystrix faunule, with above them a small portion of the Stromatoporella beds. The balance of this faunule was either eroded away, or it did not attain its full development here, for the beds of the Idiostroma zone appear a short distance away and not much above the Stromatoporella beds. The Stromatoporella beds are exposed near Portland in Cerro Gordo County, and also some two and one-half miles southwest of Nora Springs, in Floyd County. At both of these places Stromatoporella and Syringostroma are very abundant.

On the map (figs. 1, 2), the Spirifer zone is indicated at those points where there are sufficiently large areas of exposure to allow for mapping on the reduced scale here used. The large area southwest of Nora Springs is mapped as being probably Striatula beneath the glacial drift and alluvium. The area to the north, mapped as provisional Spirifer, is on the authority of Webster, as is also most of the Striatula zone area west of Mason City.

### *The Owen Sub-stage.*

#### B, III. *The Idiostroma Zone.*

The highest portion of the Hackberry stage at the type locality is composed of four to six and one-half feet of buff or buff-brown, and occasionally grayish limestone, heavily bedded, and crowded with a very slender hydrozoan that seems to belong to the genus Idiostroma. Associated with this is another species of considerably larger size and lesser abundance. There are also *Stromatoporella incrustans* (H. & W.), *S. solidula* (H. & W.) *Naticopsis gigantea* H. & W., and other gastropods. A photograph of these beds at Hackberry Grove is given here, and their contact with the beds of the Spirifer zone below is well shown. Many large blocks of this limestone have fallen from the cliff, and excellent specimens of the Idiostroma have been secured.

South and west of the main exposure and near the bank of Hackberry Creek there is another small exposure of the Idiostroma limestones. At this station specimens of *Aulopora annectens* Clarke are to be found in small numbers. In some cases this form seems to have grown on the hardened sea-mud; in others on the shells of *Naticopsis gigantea.* In the washed material composing the bed of Hackberry Creek there are large numbers of frag-

**Fig. 3.**

**Fig. 3. Hackberry Grove, Cerro Gordo County, Iowa.**

**Fig. 4.**

**Fig. 4. Contact between Idiostroma and Spirifer Zones, Hackberry Grove.**

ments of limestone from the Idiostroma zone. At the Owen Grove quarry the Idiostroma beds are to be seen in the bed of a little creek, and it is to be found also at Rockwell and other points. Besides the stromatoporoids it contains *Westernia crassa* Webster, *W. gigantea* Webster, and a large Orthoceras.

B, IV. *The Naticopsis Zone.*

The type locality for the Idiostroma zone is also the type locality for this stage, Hackberry Grove; the type locality for the Naticopsis zone and the rocks above it is the Owen Grove quarry, near Owen Creek, in Portland Township. At this point there are about thirty feet of brown or dark buff magnesian shales, limestones and argillaceous dolomitic rocks lying immediately above the Idiostroma beds and which are here referred to as the Naticopsis zone. These rocks are very fossiliferous, containing many of the species of the Spirifer zone, as well as the Cyrtoceras sp., the three described species of Westernia, and numerous unidentified gastropods. The chief distinguishing feature of the zone are the gastropods, and among these the species *Naticopsis gigantea.*

B, V. *The Acervularia Zone.*

Overlying the Naticopsis zone at the Owen Grove quarry are some twenty feet bearing numerous fragments of limestone in which are many specimens of a species of Acervularia that has been variously referred to *A. profunda, A. inequalis* and *A. davidsoni,* but which is now generally considered to be undescribed. This limestone is originally very hard, but on weathering it becomes comparatively soft and easily broken; the color is a whitish gray. It is in place, with poor exposure, near Hackberry Grove, and in the bed of Hackberry Creek are many fossils and fragments from it. The predominating feature of the zone is the corals; the undescribed Acervularia may be found in large numbers and numerous varietal forms. There are also Chonophyllum, Cystiphyllum (?), Strombodes, Alveolites, Aulopora, two new species of Heliophyllum and at least two described and two undescribed species of Pachyphyllum. There are also several undetermined species of gastropods and pelecypods, though brachiopods are quite uncommon. This zone, with a probable maximum thick-

**ness of about twenty feet, is the uppermost member of the Hackberry Stage as that formation is developed in Iowa, and to it is given the name Acervularia zone from its most characteristic and distinguishing fossil.**

**B, VI. *The Distribution of the Owen Sub-stage.***

The character of the Owen and its exposures has rendered mapping of each zone impracticable. The greater portion of the Owen as mapped here follows the investigations of Webster, while that of the extreme southern portion of Butler County is modified slightly from Arey's geological map of that county. There is some question as to how far north the Owen actually extends, and as my studies were of a more hurried and less complete character than those of Webster, I considered it best to rely entirely on him for the major portion of the formation. There will probably be necessity for revision of this portion of the map when detailed and exact studies of the distribution of the Owen in the northern counties are made.

C. *The Fossil Organisms of the Hackberry Stage.*

It is impossible to give here a complete list of the fossil species that have been found in the Hackberry, as there are large numbers that are apparently undescribed and many more that have not yet been satisfactorily identified. In my own collections are several species that I am quite sure are undescribed, and the same is true of the collections of C. Herbert Belanski, or Nora Springs, Iowa, of the University of Iowa, and of Clement L. Webster, of Charles City, who possesses the most complete representation of the Hackberry fauna and flora that is to be found. The collections of some museums, as the Walker Museum of the University of Chicago, the American Museum of Natural History, and the U. S. National Museum also contain undescribed Hackberry material, but nothing, probably, that is not represented in the collections of Webster, Belanski and the writer.

This list is, therefore, of such a character that it probably includes most of the identified species from the Hackberry; some of the most striking or most prominent of the unidentified forms, and a number of the species that are apparently undescribed. In order to make more clear the faunal characters of the divisions here made in

the formation the list has been so divided as to give one list for the Owen sub-stage; one for the Spirifer zone, and one for the Striatula zone. In comparing these lists it should be borne in mind that in the Spirifer zone the brachiopods were very numerous, as were also the rugose corals, while in the Owen these same forms were comparatively uncommon. Thus though we have several species common to both, they were much more sparsely scattered in the Owen than in the Spirifer.

In several cases I have reduced species to varieties, because these "species" so intergraded with other forms that a true specific distinction was lacking. Of such are *Strombodes johanni multiradiatus, Strophonella reversa hybrida,* and *Atrypa reticularis hackberryensis* of this list.[3]

I.—*Fossil Species of the Owen sub-stage.*

PLANTÆ

"Fucoids" of at least two species, undetermined.

ANIMALES

*Coelenterata*

Cliona sp. undet. Large boring forms found in Stromatoporella, Alveolites, Pachyphyllum and Acervularia.

*Anthozoa*

Heliophyllum n. sp.
Heliophyllum, two undetermined species.
Chonophyllum ellipticum H. & W.
Chonophyllum sp. undet.
Zaphrentis solida H. & W.
Cystiphyllum mundulum H. & W.
Charactophyllum nanum (H. & W.)
Strombodes johanni (H. & W.)
Strombodes johanni multiradiatus (H. & W.).[4]
Acervularia inequalis H. & W.
Acervularia "inequalis" (n. sp.?).
Acervularia n. sp.[5]
Pachyphyllum woodmani (White).
Pachyphyllum woodmani (White) n. var.
Pachyphyllum crassicostatum Webster.
Pachyphyllum crassum Webster.

[3] In this list, the abbreviations *n. var.* and *n. sp.* have been used to designate those species and varieties *new and undescribed, or apparently undescribed.*

[4] Described as *Smithia multiradiata* (23d Annual Report, N. Y. State Cabinet), and has later been referred to as *Strombodes multiradiatus* (H. & W.). The distinction *S. johanni* (H. & W.) is not sufficient to warrant specific distinction, and I here consider '*multiradiatus*' as a variety of *johanni.*

[5] The typical Acervularia Zone species.

Alveolities rockfordensis H. & W.
Cladopora robusta Rom. (?)
Aulopora iowensis H. & W.
Aulopora cf. saxivadum H. & W.
Aulopora annectens Clarke.
Aulopora cf. serpens Goldf.
Aulopora n. sp.?
Syringopora sp. undet.

*Hydrozoa* (?)
(Stromatoporoidea).
Stromatoporella solidula (H. & W.).
Stromatoporella incrustans (H. & W.).
Syringostroma (?) planulatum (H. & W.).
Idiostroma two sp. undet.

*Vermes*
Spirorbis omphalodes Goldfuss.
Forms probably belonging to the Tubulifera.

*Echinodermata*
sp. undet.
Melocrinus sp. undet.

*Bryozoa*
Hederella alternata (H. & W.).
Hederella sp. undet.
Lioclema (?) sp.

*Brachiopoda*
Schizophoria striatula (Schloth.).
Leptostrophia canace (H. & W.).
Strophonella reversa Hall.
Productella hallana Walcott.
Atrypa reticularis (Linnæus).
Atrypa hystrix Schloth.
Atrypa hystrix planosulcata Webster.
Spirifer orestes H. & W.
Spirifer (?) hungerfordi Hall.
Spirifer whitneyi Hall.

*Pelecypoda*
Paracyclas validalinea Webster.
Paracyclas sabini White.
Paracyclas elliptica Hall, var.
Leptodesma sp. undet.

*Gastropoda*
Bellerophon sp. undet.
Straparollus cf. cyclostamus Hall.
Ceneostoma, sps. undet.
Pleurotomaria sp.
Diaphorostoma lineatum (Con.).
Floydia concentrica Webster.
Naticopsis gigantea H. & W.

Naticopsis gigantea H. & W. var.
Westernia crassa Webster.
Westernia owenensis Webster.
Westernia gigantea Webster.

*Cephalopoda*

Orthoceras sp. undet.
Cyrtoceras sp. undet.

II.—*IIa: Fossil species of the Spirifer zone.*

PLANTÆ

"Fucoids," of three or more species.

ANIMALES

*Coelenterata*

Cliona hackberryensis Thomas.
Cliona sp. undet.

*Anthozoa*

Zaphrentis solida H. & W.
Heliophyllum scrutarium Clarke & Swartz.
Cyathophyllum sp. undet. (nov. ?).
Cystiphyllum mundulum H. & W.
Charactophyllum nanum H. & W.
Strombodes johanni (H. & W.).
Strombodes johanni multiradiatus (H. & W.).
Pachyphyllum woodmani (White).
Pachyphyllum woodmani, cf. gregarium Webster.
Pachyphyllum crassicostatum Webster.
Pachyphyllum n. sp.
Pachyphyllum ordinatum Webster.
Pachyphyllum crassum Webster.
Macgeea solitaria (H. & W.).
Macgeea parva Webster.
Macgeea culmula Webster.
Acervularia inequalis H. & W.
Acervularia profunda Hall.
Acervularia n. sp. (cf. inequalis).
Chonophyllum ellipticum H. & W.
Chonophyllum n. sp.
Alveolites rockfordensis H. & W.
Cladopora robusta Rom.
Cladopora cf. palmata H. & W.
Aulopora iowensis H. & W.
Aulopora saxivadum H. & W.
Aulopora filiformis Billings.
Aulopora, several new (?) species.
Syringopora n. sp. (?).

*Hydrozoa* (?)

Stromatoporella solidula (H. & W.).
Stromatoporella incrustans (H. & W.).

Actinostroma cf. expansum (H. & W.).
Actinostroma n. sp.
Syringostroma (?) planulatum (H. & W.).

*Vermes*

Serpularia, several unidentified species.
Cornulites, unidentified species.
Spirorbis omphalodes Goldfuss.
Spirorbis arkonensis Goldfuss.
Specimens, probably of the Tubulifera.

*Echinodermata*

sp. undet.
Melocrinus sp. undet.
Other undetermined crinoids, totalling about ten species (Webster).
Nortonechinus n. sp.
Echinoids undetermined.

*Bryozoa*

Vinella (?) sp. undet.
Hederella alternata (H. & W.).
Hederella sp., cf. filiformis Nicholson.
Lioclema occidens (H. & W.).
Lioclema minutissimum Hall & Clarke.
Fenestella vera Ulrich.
Fenestella n. sp. (?).
Eridotrypa n. sp.

*Brachiopoda*

Crania famelica H. & W.
Crania famelica n. var.
Crania crenistriata Hall.
Schizophoria striatula (Schloth.).
Schizophoria striatula impressa (Hall).
Leptostrophia canace (H. & W.).
Leptostrophia perplana nervosa (Hall).
Stropheodonta n. sp. (cf. calvini Miller).
Stropheodonta exilis Calvin.
Stropheodonta (variabilis Calvin).
Douvillina arcuata (Hall).
Douvillina arcuata maxima Fenton.
Strophonella reversa Hall.
Strophonella reversa gravis Fenton.
Strophonella reversa hybrida (Hall).[6]
Schuchertella parva (Hall).
Schuchertella chemungensis (Con.) ?
Productella hallana Walcott.
Productella truncata Hall.

[6] Described as a distinct species (23d Ann. Rep. N. Y. State Cab.). This form intergrades to such an extent with the earlier, and more clearly defined species *S. reversa* that it is here placed as a variety of that species.

Productella speciosa Hall.
Gypidula comis munda (Calvin).[7]
Gypidula comis (Owen) n. var.
Rhynchonella subacuminata Webster.
Camarotœchia contracta saxatilis Hall.
Rhipidomella cf. penelope Hall.
Pugnoides altus (Calvin).
Pugnoides ambiguus Calvin.
Liorhynchus iris Hall.
Liorhynchus sp. undet.
Centronella navicella (Hall).
Cranaena calvini (H. & W.).
Atrypa reticularis (Linnaeus).
Atrypa reticularis hackberryensis (Webster).[8]
Atrypa reticularis alta Fenton.
Atrypa reticularis n. var.
Atrypa hystrix (Schlothein).
Atrypa hystrix planosulcata Webster.
Atrypa spinosa Hall ?
Atrypa aspera Hall.
Atrypa aspera elongata Webster.
Spirifer whitneyi Hall.
Spirifer whitneyi productus Fenton.
Spirifer whitneyi gradatus Fenton.
Spirifer whitneyi rockfordensis Fenton.
Spirifer, cf. fornacula Hall.
Spirifer orestes H. & W.
Spirifer orestes websteri Fenton.
Spirifer cyrtinaformis H. & W.
Spirifer cyrtinaformis helenæ Fenton.
Spirifer macbridei Calvin.
Spirifer (?) hungerfordi Hall.
Spirifer (?) septentrionalis Webster.[9]
Cyrtina hamiltonensis recta Hall.
Reticularia n. sp. (called R. fimbriata (Con.)).
Athyris, cf. minutissima Webster.

*Pelecypoda*

Gramysia sp. undet.
Sphenotus contractus Hall (?)
Leptodesma sp. undet.
Lucina (?) sp.
Paracyclas sabini White.

[7] Described by Calvin as *Gypidula munda;* later (Ia. Geol. Surv. VII) referred to by him as not widely different from *G. comis,* and here placed as a variety of that species.

[8] Described as *Atrypa hackberryensis,* but not specifically distinct from *A. reticularis* as at present understood.

[9] Originally described as *Spirifer northerna* Webster. The name is here changed by the author of the species, C. L. Webster.

Paracyclas validalinea Webster.
Paracyclas elliptica Hall.
Glossites lingualis Hall.
Pterinopecten sp. undet.
Aviculopecten sp. undet.

*Gastropoda*

Bellerophon sp. undet.
Straparollus cyclostomus (Hall).
Straparollus sp. undet.
Platyostoma (?) insolitum Webster.
Platyostoma (?) modestum Webster.
Platyostoma (?) antiquum Webster.
Diaphorostoma cf. ventricosum (Con.).
Cyclonema sp. undet. (nov. ?).
Pleurotomaria verticillata Webster.
Holopea (?) iowensis Webster.
Naticopsis gigantea H. & W.
Naticopsis gigantea hackberryensis Webster.[10]
Naticopsis gigantea websteri nom. nov.[11]
Naticopsis magnificentis Webster.
Floydia concentrica Webster.
Floydia concentrica multisinuata Fenton.
Loxonema hamiltonensis Hall.
Loxonema cf. pexatum Hall.

*Cephalopoda*

Orthoceras berryx Hall.
Orthoceras consortale Hall.
Orthoceras sp. undet.
Gomphoceras sp. undet.
Manticoceras pattersoni (Hall).

*Foraminifera*

Various undetermined forms.

*Pisces*

Ptyctodus calceolus H. & W.
Dinichthys pustulosus Eastman.
Diplodus striatus Eastman.
Diplodus priscus Eastman.
Apsidichthys sp. undet.

*IIb: Fossil species of the Striatula zone.*

PLANTÆ

"Fucoids," of two or three undetermined species.

[10] Described as *Naticopsis hackberryensis* by Webster. I do not consider the distinction of this form from *N. gigantea* H. & W. sufficient to make it more than a variety. (Described in Iowa Naturalist, vol. 2, p. 3.)

[11] Described as *Naticopsis gigantea* var. *depressa* by Webster, Iowa Naturalist, Vol. 2, p. 3. The name was preoccupied by *Naticopsis depressa* Winchell, 1863, and therefore the new name *websteri* is here proposed for the variety.

ANIMALES

*Bryozoa*

Lioclema occidens (H. & W.).
Various undetermined species.

*Brachiopoda*

Crania famelica H. & W.
Stropheodonta (Leptostrophia) canace H. & W.
Douvillina arcuata (H. & W.).
Gypidula comis (Owen).
Cranæna calvini (H. & W.) ?
Centronella cf. navicella (Hall).
Schizophoria striatula (Schloth.).
Atrypa reticularis (Linn.).
Atrypa reticularis (Linn.) var. cf. alta Fenton.
Atrypa hystrix Schlotheim.
Spirifer whitneyi Hall.
Spirifer whitneyi gradatus Fenton (?)
Spirifer (?) hungerfordi Hall.
Athyris minutissima Webster.

*Pelecypoda*

Glossites sp. undet.
Grammysia (?) sp. undet.
Paracyclas validalinea Webster.

*Gastropoda*

Platyostoma mirum Webster.
Platyostoma pervatum Webster.
Platyostoma sp. undet.
Platyostoma, nov. spec.
Naticopsis rara Webster.
Turbo (?) strigillata Webster.
Turbo (?) incerta Webster.
Holopea tenuicarinata Webster.
Cyclonema brevilineata Webster.
Cyclonema subcrenulata Webster.

*Foraminifera*

Various undetermined species.

### D. *The Age and Relationships of the Hackberry.*

There are two geologic formations in this country whose faunas have been considered as being related to that of the Hackberry; the Independence Shale of Iowa, and the High Point beds of New York. Dr. Calvin was so impressed with the first of these relationships that he even considered that: "During the time represented by the shales and limestones that lie between the Independence and the Lime Creek shales the peculiar fauna of the lower shale horizon, adapted to life on a muddy sea

bottom, persisted in some congenial localities at present unknown, suffering in the meantime only a very slight amount of modification, and again appeared, reinforced by a number of other species, when the sea bottom offered conditions favorable to its success." (Ia. Surv. VII, pp. 169-170.)

Even if the actual connection between the Hackberry and Independence faunas were as close as Calvin thought it to be, this theory of the origin of the Hackberry would be rather far-fetched. But upon examination of series of Independence material it will be found that even in those species that are common to both formations there is considerable variation in form. This variation may be of merely varietal importance, as in *Productella hallana* Walcott, or it may be of such importance that specific separation would be justified and desirable. In general it may be said, therefore, that the connection between the Independence and the Hackberry—one based at best on less than fifteen species—is too small to be of any importance.

In the case of the High Point beds there is probably more evidence of faunal connection, as shown by Clarke in Bulletin 16 of the U. S. Survey, though at best the number of species (following Clarke) is not above sixteen or seventeen. When this number is compared with the not less than two hundred-fifty fossil forms to be found in the Hackberry, the futility of any attempts at correlation of the two formations may be easily seen. As the supposed relationship with the Independence was one of faunas only, without attempt or possibility of correlation, it is apparent that the Hackberry is a separate and distinct stage, with no known equivalent.

The age of the Hackberry has been variously given as Hamilton, Portage, Chemung and even as Kinderhook. Actually it is of the latest Devonian age, of the Chautauquan series, and is the most recent of any of the Devonian formations of the Dakotan province. Webster regards it as being of practically the same age as the Ouray limestones of the west; indeed he regards the latter as laid down by another division of the same body of water that developed the Hackberry. The extent of the Hackberry, previous to erosion, is of course unknown. In all probability, however, it was much greater than is now indicated by exposures.

E. *Summary.*

*1.*—The highest position in the Devonian of Iowa, as well as the youngest, is occupied by a series of shales, limestones and dolomitic beds reaching a maximum thickness of something over one hundred feet.

*2.*—This formation rests upon some ninety feet of bluish, clayey shale, here called the Sheffield Formation, which is unrelated to it, and from which it is separated *by a rather poorly marked unconformity.*

*3.*—These hundred feet of shales, limestones and dolomitic beds comprise a distinct stage, the Hackberry, with a very rich and prolific fauna characteristic of this stage.

**Walker Museum, University of Chicago.**

ART. XXV.—*Tactite, the product of Contact Metamorphism;** by FRANK L. HESS.

Probably every geologist who has worked among contact metamorphosed rocks has felt the need of a single word by which to designate the alteration product that has resulted when soluble rocks have been acted on by gases, solutions and heat accompanying the intrusion of granitoid masses. I have felt this need particularly in a study of the contact metamorphic tungsten deposits of the United States, in which I have been associated with Mr. E. S. Larsen.

In describing the altered rock it became very irksome to continually refer to the "contact metamorphosed rock" and to try to find some variation of the phrase that would mean the same thing. The tungsten miners in western Nevada and eastern California have shown the need of such a term by christening the rock "garnetite," for in some localities the deposits are composed largely of garnet, but some of the contact metamorphic tungsten deposits contain little or no garnet, and the word is for such rocks a misnomer. Thus, a contact metamorphic tungsten deposit in the Grouse Creek Mountains of northwestern Utah is mostly clinozoisite, and garnet, if present, is a rarity. In other deposits there may be a more or less great preponderance of mica, epidote, diopside hornblende, or even pyrrhotite, accompanied by numerous minor minerals. In other types of contact metamorphic deposits the prevailing mineral may be, at least locally, quartz, calcite, specular hematite, magnetite, chalcopyrite, pyrite or vesuvianite. With all the variations, however, that the deposits may show from place to place, even in parts of the same altered mass, the characteristics are so plain to the geologist acquainted with this type of rock that it is at once recognizable.

The minerals mentioned are largely formed from materials introduced by the solutions that caused the metamorphism, and form a zone beyond which is another zone that has a simpler mineralogy in which wollastonite or tremolite, and recrystallized calcite are the principal minerals. This zone is of little economic interest, but the zone receiving the bulk of introduced materials is in

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many places of commercial value for the introduced metals—immigrants from the invading rock—including gold, silver, lead, copper, bismuth, zinc, tungsten and molybdenum.

For the rocks of the complexly mineralized zone, I propose the name "tactite," derived from the Latin "*tactus,*" (touching). It is a word which will not, of course, like granite and similar words, when used in a narrow sense, mean a rock of a fairly definite composition, but will be a class or group name like gneiss, schist, hornstone, porphyry, or lava.

Tactite may be defined as a rock of more or less complex mineralogy formed by the contact metamorphism of limestone, dolomite or other soluble rocks into which foreign matter from the intruding magma has been introduced by hot solutions or gases. It does not include the inclosing zone of tremolite, wollastonite and calcite.

ART. XXVI.—*Structural Features of the Abajo Mountains, Utah;* by MALCOLM RUTHERFORD THORPE.[1]

The Sierra Abajo, or "Blue Mountains," of San Juan County, Utah, occupy a roughly circular area of about 150 square miles nearly in the center of the Canyon Lands section of the Colorado Plateau physiographic province. They rise abruptly 3,000 to 4,000 feet above the encircling plain, presenting a prominent land mark from all directions. The Abajo Mountains comprise a group of laccoliths with associated sheets and dikes. The intrusive bodies composed chiefly of hornblende-latite porphyry show a remarkable similarity in mineral content and megascopic appearance and undoubtedly came from a common reservoir.

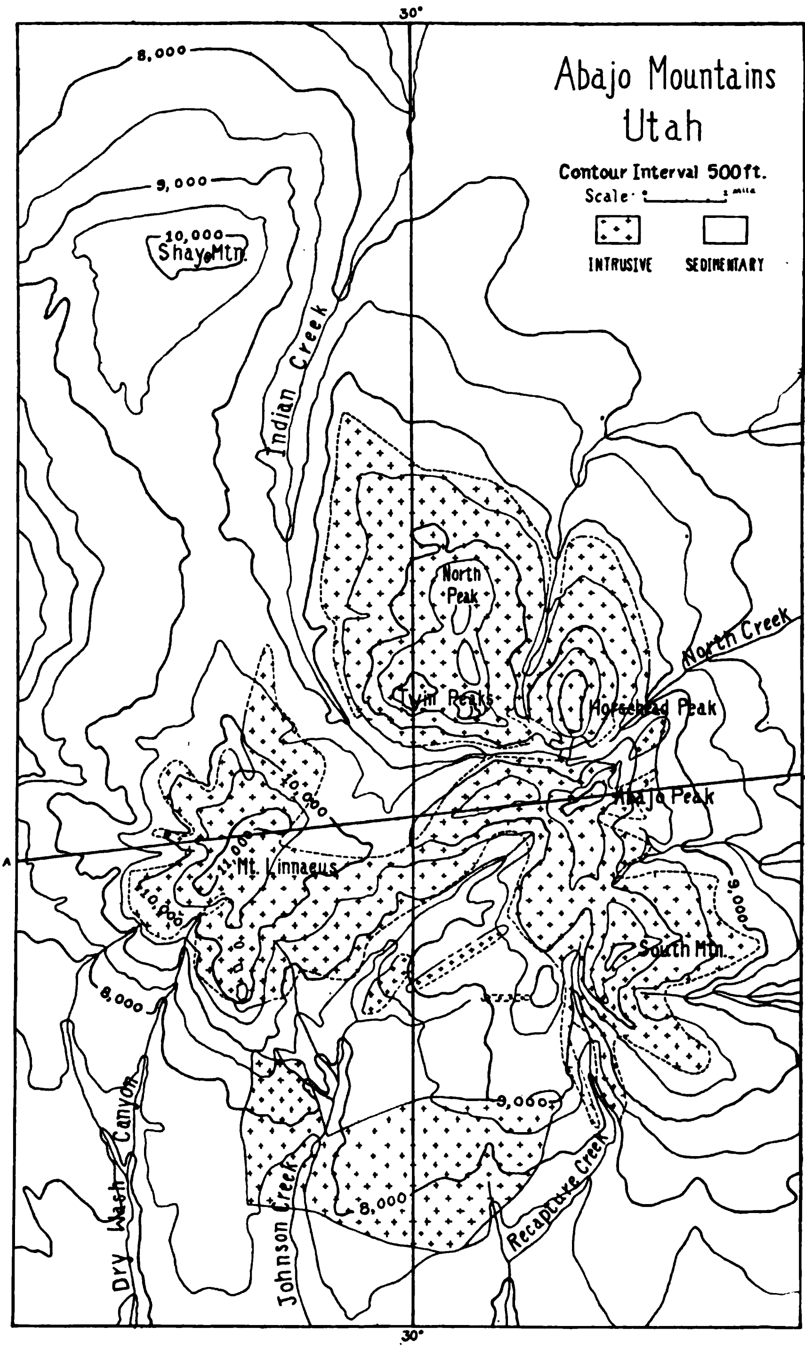
*Detailed Structure.*

The Abajo group will be divided into four sections, as follows: 1. Shay Mountain, northwest section; 2. Mt. Linnæus, western section; 3. The southern area, including Abajo and South Peaks, and the region east of Johnson Creek, and 4. The northern area, comprising Horsehead, North and Twin Peaks.

1. *Shay Mountain* is essentially a dome of sedimentary rock. At its crest is an outcrop about 110 square yards in area of blue porphyry, identical in composition with the rock forming the main mass of the Abajo Mountains. This outcrop is probably a plug or short dike which has broken through the roof of the laccolithic chamber. The dimensions are approximately 50 feet north and south and between 15 and 25 feet in an east-west direction. Dakota sandstone is the highest formation now present in the area. Strata of McElmo and La Plata are exposed on the flanks in steep-walled ravines and canyons. The dip of the strata of the dome to the east is 12°, to the south 5°, to the west 9°, while on the north they dip 15° and then flatten out to 5°. It is thought that the magma insinuated itself between strata of the Chinle formation, but erosion has not cut deeply enough to prove this. A Dakota-capped synclinal ridge,

[1] The detailed geologic work on which this paper is based was done during the summer and fall of 1915 under the supervision of Professor Herbert E. Gregory; the complete report has been submitted for publication to the U. S. Geological Survey. This article is published with the permission of the Director of the Survey.

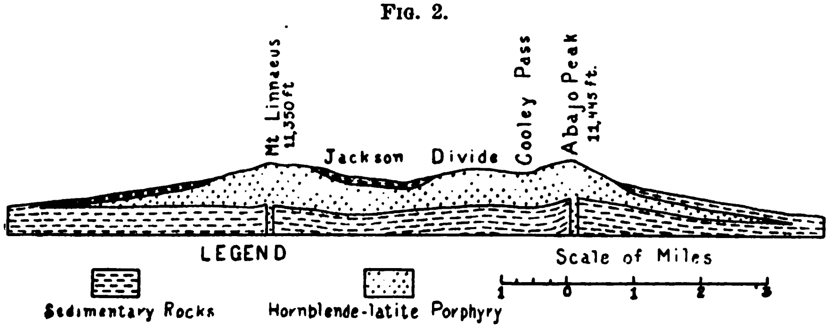
Fig. 1.


30°
Abajo Mountains
Utah
Contour Interval 500 ft.
Scale
INTRUSIVE
SEDIMENTARY
8,000
9,000
10,000
Shay Mtn.
Indian Creek
North Peak
Twin Peaks
North Creek
Horsehead Peak
Abajo Peak
A
A'
Mt. Linnaeus
11,000
10,000
9,000
South Mtn.
8,000
9,000
Dry Wash Canyon
Johnson Creek
8,000
Recapture Creek
30°

the axis of which runs east and west, joins Shay mountain and Mt. Linnæus. The pitch of the axis is toward the west and does not exceed 2° or 3°. The Dakota sandstone forms a dip slope on the south side of Shay Mountain and the same on the north slope of Mt. Linnæus.

2. *Mt. Linnæus* (fig. 3) is a partially uncovered laccolith. The Dakota sandstone overlaps the northeastern section, but no lower formation is exposed, whereas on the other sides of the mountain from 200 to 250 feet of upper McElmo are upturned beneath the Dakota sandstone, hence the horizon of intrusion is most probably middle McElmo, except on the northeastern side. If the lower Cretaceous and Upper Jurassic strata were projected

Fig. 2.




over the mountain in accordance with the dips now found they would form the cover of the laccolith with no difficulties. Patches of the roof rock are present in several places at all elevations on the mountains.

3. *The Southern Area.*—The Dakota and Upper McElmo formations flank the mountain sides to varying heights so that these peaks are by no means well exposed except near their summits. On the south and east sides the Dakota slopes up with a gentle but constantly increasing dip away from the mountains until it reaches well up their flanks. Here the Dakota and Upper McElmo formations unquestionably formed the cover at the time of intrusion. On the eastern side several prominent spurs extend outward and the dip of the strata flanking them is as high as 45° east, although dips ranging from 35° E. to 41° E. are common.

4. *The Northern Area.*—The horizon of intrusion in the case of North and Twin Peaks as well as the western part of Horsehead Peak was at or near the base of the

Mancos shale. Only on the east side of Horsehead Peak does the Dakota overlap the igneous rock. Fossils found in metamorphosed shale near the summit of North Peak, 11,350 feet high, were identified by Dr. Stanton as Middle Mancos. Isolated tilted blocks of Mancos shale lie at different altitudes, dipping in various directions and at different angles. At the mouth of North Canyon the Dakota and porphyry are in contact, the former dipping 80° northwest at the contact, decreasing to 16° E. about 200 feet from this point, and then sloping away for several miles, gradually flattening out, and merging into the regional dip of the plain. The Dakota sandstone is apparently the floor of the laccolith except on the eastern side where the magma, instead of breaking through, arched up the sandstone as in the case of the southern half of the group.

FIG. 3.

FIG. 3. Eastern slope of Mount Linnæus.

Between Johnson and Recapture Creeks a large sheet of dacite outcrops. It is an offshoot of the magma forming the major intrusions. Its roof has been very nearly removed by erosion, but many isolated patches of Dakota sandstone as well as some strata of the McElmo still remain.

*Faults.*

In the Abajo area faulting is rarely found, whereas none was noted by Emery in the Carrizo Mountains of Arizona and but few faults were described by Gilbert as a result of his studies in the Henry Mountains. The most noticeable fault of the Abajo area is south of South Peak. It trends nearly north and south and hence lies at right angles to the main intrusion. The eastern wall of Recapture Canyon at this place is the steep western escarpment

Fig. 4.

Fig. 4. Upturned La Plata sandstone; south side of Abajo Mountains.

of the fault. This block is broken from similar strata on its southern boundary by another fault, trending at right angles to the major one and running parallel with the uplift. These faults form a block whose surface dips 12° to the east until it merges with the regional dip of 3° east. The maximum amount of throw was about 500 feet. Marginal faults may be seen in many places where blocks have been broken off and carried either up to the mountain summits or high up their flanks. Slickensided surfaces are common in the roof rock indicating a considerable amount of movement during the adjustment of the cover.

*Structural Valleys.*

The major stream channels, carved in sedimentary strata, have been determined by synclinal valleys. Near the head of Johnson Creek on the east bank, the Dakota sandstone dips 26° ± SW, strike N. 45° W., while in the bed of the creek near this point, the strata of the McElmo formation dip 6° S, strike E-W and on the west side of the creek the Dakota dips southeast at varying angles. North Canyon is another syncline, the floor of which is Dakota sandstone. On the east side of Horsehead Peak the strata dip to the east at high angles, slopes of 45° being common, while in the creek bottom they dip down-stream and on the east side of the canyon are steep westerly slopes. Indian Creek has cut through the Dakota and McElmo formations along a line of weakness due to faulting caused by the uplift of North and Shay Mountains on opposite sides of the creek.

*Floor.*

The floor of the Abajo group is slightly visible in two localities; one in Hop Creek on the northwest slope of Mt. Linnæus and the other in Recapture Creek. Both of these exposures are very much obscured by talus and do not furnish sufficient data for a definite statement that the floor or floors is or are even or uneven, but in the writer's opinion they are uneven for the following reasons:

1. In this system there are a group of laccoliths, with both vertical and horizontal distribution, as determined from their position and structure. Hence part of the floor of one is the uneven roof of the laccolith next below.
2. The general structure of the region shows folding and faulting near the Abajo area and it is now generally agreed that very little, if any, of those phenomena have taken place since the uplift of the group.
3. Hayden, in a section through this area, constructed after his studies in 1876, drew an uneven floor with the west side much higher than the east.[2]
4. There is a difference in elevation between the same horizons on the west and east sides of the group of between 1,500 and 1,750 feet, the higher level being invariably on the west. Emery noted like evidences of the antecedent structures in the Carrizo Mountains.

[2] Hayden, F. V.: Geol. and Geog. Atlas of Colorado and portions of Adjacent Terr. 1877, Sheet XVII, sections to accompany Sheet XV.

5. Several monoclines south and southwest of the Abajo area are considered by Gregory to be of pre-Tertiary age, while the uplift of the mountains is regarded as having taken place in the Tertiary.

The above considerations offer two lines of argument in support of the theory of an uneven floor for this group. The first depends upon the irregular vertical and horizontal distribution of the laccoliths and the second involves the antecedent structures, existing on all sides of the area, which apparently underlie the superimposed igneous masses.

*Roof.*

The roof of the Shay Mountain laccolith is lower than the base of the La Plata, since this formation is involved in the doming. It is impossible to determine at what depth lies the horizon of intrusion for erosion has not cut sufficiently deep into the uplift. Upper McElmo and Dakota formations roof the southern and western sections of the Sierra Abajo, while the northern half was covered by Mancos shale. Since the crests of the mountains are either uncovered or still retain only isolated patches of the roof rock, the former configuration of this roof cannot be definitely known. From the shape of the igneous mass, which does not present any marked irregularities on its upper surface, and from dips of the sedimentary areas on and at the base of the uplifts, it is inferred that the roof was fairly regular and but slightly faulted as shown by the tilting to which some of the residual roof blocks have been subjected.

A considerable thickness of strata has been eroded from the cover of the laccoliths and only metamorphosed remnants of the roof now remain. From the data furnished by these residual masses it is evident that Dakota and McElmo strata and in all probability Mesa Verde sandstone also formerly covered the laccoliths. It remains to be demonstrated whether any Tertiary or later sediments were ever deposited over this area, for none now exist except alluvial deposits which were laid down since the intrusion. The lowest strata observed in contact with the intrusive rock are the McElmo (Jurassic), while the highest formation is the Middle Mancos (Benton). It is not known that the Mesa Verde (Upper Cretaceous) covered this area at the time of intrusion of the

magma, so that in estimating the thickness of the cover, the top of the Mancos shale will be used as the datum plane. Hence the depth of the cover over the Shay Mountain laccolith must have been not less than 2,750 + feet, while the depth over the northern area of the Abajo group was not less than 1,200 + feet and over the southern and western sections about 1,500 feet. In the Carrizo area Emery estimated a depth of between 2,000 and 5,000 feet for the depth of the cover over that mountain. Gilbert, in restoring the roofs of the laccoliths which comprise the Henry Mountains, found a depth of about 3,500 feet for the laccoliths of the upper zone and for those of the lower zone nearly 7,000 feet. Gilbert considered that all of the Cretaceous beds covered the laccoliths of the Henry Mountains. In all probability they also covered the Abajo group and in that case from 800 to 1,000 feet of strata must be added to the writer's estimate of the depth of the cover over that region.

*Summary of proof of laccolithic origin for the Abajo group.*

Criteria in support of the theory of laccolithic origin for the Abajo group have been carefully studied in the field and in the laboratory and the results will be briefly presented below:

A. *Factors in the igneous mass of the Abajo group which tend to prove an intrusive origin.*

1. Porphyritic texture is most common, indicating that the rock cooled at considerable depth to allow the phenocrysts to form in place, to assume their crystal forms and to attain considerable size. 2. Specimens of rock gathered at various horizons in the laccoliths and at different localities show a remarkable similarity both in composition and structure. 3. There is an absence of all extrusive characteristics, such as amygdaloidal and vesicular structures. 4. Laccoliths of this area are in association with dikes, sheets and other igneous bodies which have a crosscutting relationship to the sediments. The origin of these phenomena is clearly intrusive. Some of the dikes cut through the cover of the laccolith and hence the igneous mass must have been intruded.

B. *Factors in the sediments associated with the igneous rock which point to an intrusive origin for the latter.*

1. At every locality where the igneous mass is in visible contact with the sedimentary strata, the latter are meta-

morphosed. Not only is this true of the lower, but also of the upper contacts. 2. There is an entire absence of fragments of the igneous rock in the overlying sediments. 3. The strata which flank the mountain have unquestionably been disturbed since their deposition. 4. The presence of a floor in the Abajo group seems practically certain, although it is not entirely capable of proof, unless, from the two small areas where it is visible, it can be said to be characteristic of the whole mass. 5. The northern and northwestern sections of the group have been intruded at different horizons in the sedimentary strata than have the southern and eastern sections. 6. On the crests of the laccoliths masses of sediments, over 100 feet thick, dip at various angles from the horizontal and are highly metamorphosed.

C. *Factors not closely associated with either the intrusion or its cover, but which point to intrusion in the region.*

1. Distribution of the laccoliths in a group instead of in a system. This is characteristic of all laccolithic intrusions and is found in the Henry, Carrizo, La Sal and other mountains of this type as well as in the Sierra Abajo. 2. There is an entire absence of tuffs, breccias, lava flows, volcanic bombs, lapilli, etc., in fact all the phenomena which are so characteristic of extrusion. In conclusion all the phenomena are those of intrusion and no evidence has been found pointing to extrusion in this area.

### *Contact Metamorphism.*

Contact metamorphism has taken place in the Abajo area to a very limited extent. The endomorphic effects have been very slight. In some cases the igneous rock becomes of finer grain near the contact; in others it is more porphyritic, both of which phenomena are indicative of more rapid cooling. There is no indication that new minerals have been developed. The exomorphic effects have resulted in baking and hardening the overlying and other strata in contact with the laccolithic masses. The sandstones have been changed to quartzites and the shales to hornfels and argillites, but still retain all of their original structures, such as crossbedding, bedding planes and conglomeratic and granular structures. Almost no mashing or distortion of the sediments in contact with the igneous rock could be observed. This hardening of the sedimentary strata has made them tougher than the igne-

ous rocks so that they resist erosion and stand out as revetcrags, ridges and other topographic forms. The effects of the metamorphism is felt from 10 to 200 feet from the contact, depending upon the size of the laccolith with which it is in association. The effect produced in the igneous rock is apparent only a few feet at the most from the contact. Megascopically, the three formations, McElmo, Dakota and Mancos, have neither gained nor lost any element in their mineral content other than being slightly mineralized in very thin bands close to the contact.

### *Cause of the lack of intense Contact Metamorphism.*

It is apparent from the above discussion that contact metamorphism has not been an important factor in the geology of the Abajo Mountains. In the Carrizo area Emery states that the effects of metamorphism "are commonly not noticeable at a distance of more than three feet from the contact,[3] and Gilbert, in the Henry Mountains, found many instances where no difference could be detected between specimens collected at the contact and at the interior of the laccolith, while the original structures of the enveloping rocks have not been altered, although they have been indurated. This phenomenon is characteristic of laccoliths in the Southwest and Cross attributes it to the lack of the mineralizing agents, chlorine, fluorine and superheated steam in the magma.[4] The conditions of metamorphism in the Abajo area are believed to be due to this cause.

### *Manner of Intrusion.*

No evidences of stoping or assimiliation have been found in this area, and from this and other facts above mentioned, it seems conclusive that the Sierra Abajo owe their origin to intrusion. The character of the hornblende-latite porphyry of the Abajo Mountains is very uniform and it seems reasonable to suppose that all of the laccolithic material came from a common reservoir. In regions where the strata are practically undisturbed except by intrusions, as in central Montana and southeastern Utah, the magma must have been aggressive,

[3] Emery, W. B.: this Journal, 4th Ser., vol. 42, p. 363, Oct., 1916.

[4] Cross, Whitman, Spencer, A. C., Purrington, C. W.: U. S. Geol. Surv., La Plata folio, No. 60, Geol. Atlas of U. S., p. 11, 1899.

insinuating itself between and doming the strata to form a laccolithic chamber. From all of the data at hand, it is justifiable to call the Abajo Mountains a group of laccoliths, coming under the head of injected bodies in Daly's classification of intrusive igneous masses.

### *Age of Intrusion.*

There is an unanimous opinion among all students of the laccoliths of the Southwest that they are Tertiary in age, most probably Early Tertiary in the Late Laramie time, and the Laramide Revolution was responsible for their intrusion. There are certain structures, such as the Comb Monocline, of pre-Tertiary age in this area and these have been magnified by the intrusions. Hence the Abajo laccoliths were formed subsequent to these antecedent structures and hence can not be earlier than Tertiary. Again the intrusions took place subsequent to the deposition of the Middle Cretaceous and there seems to be no valid reason to doubt that all of the Upper Cretaceous likewise covered the area at the time of intrusion. Further than this it is impossible to date the intrusion due to the lack of any Tertiary deposits over this area. The age of the individual laccoliths, sheets and dikes, with respect to one another, could not be determined as they were not observed cutting each other.

**New Haven, Conn.**

# SCIENTIFIC INTELLIGENCE.

## I. Chemistry and Physics.

1. *The Single Deflection Method of Weighing.*—It is very satisfactory to notice the advocacy of a simple method of analytical weighing by Paul H. M.-P. Brinton, of the University of Arizona, because several authoritative, recent text books on quantitative chemical analysis recommend the very cumbersome and exceedingly laborious method of very long swings of the balance beam with elaborate observations, in the place of the undoubtedly more accurate and far more convenient use of very short swings. The method under consideration was brought to the attention of its present advocate a number of years ago by Dr. F. N. Guild of the same University, who had used it for many years but could not give the source from which it came. The present author was sceptical about it and refused even to try it for 10 years, but now is strongly in its favor.

The method of weighing is carried out by adjusting the unloaded balance so that when the pans are carefully released the pointer will swing out 3 divisions or more to the right to a definite place. A single excursion of the pointer is the only one observed. Then in weighing an object the weights are applied so that the pointer makes a single excursion to the same extent. Records are given of consecutive single swings, with balances empty and loaded, which show that a high degree of accuracy is obtainable by this method.

The reviewer for a great many years has been in the habit of observing the first excursion of the balance pointer when near equilibrium in order to decide upon the proper position in which to place the rider for the exact weight, but he uses finally very short swings of a single division or less on each side of the center of the scale. It is his experience that with rapid work a slight impulse is likely to be imparted to the balance in one direction or the other by the release of the pans, so that he prefers to watch the return of the pointer from its first excursion. If this excursion has been a short one of not more than two or three divisions, so that the retardation of a single swing is inappreciable, and the pointer returns to the exact center of the scale, the indication is correct, but if the pointer does not reach the center, or if it passes that point, the deficiency should be added to the first swing, or the excess should be deducted from it, to find the proper indication. It appears to be a usual practice among gold and silver assayers to adjust their very accurate and delicate balances so that the zero point is indicated by a definite swing, say of 2 divisions to the right and then back to the center. This practice corresponds to the method under con-

sideration provided that it is certain that the pointer will always return to the same place. It is not intended to criticize adversely this method of weighing, for with the proper precautions it will evidently give good results, but it is believed that observations of the return swing would obviate uncertainties in the action of the pan-arresters, would make the manipulation of the latter less tedious, and would usually increase the ease, rapidity and certainty of weighing.—*Jour. Amer. Chem. Soc.* **41**, 1151.

H. L. W.

2. *A Method of Growing Large Perfect Crystals from Solution.*—R. W. Moore, of the Research Laboratory of the General Chemical Co., has described a very satisfactory method for this purpose. He refers to other methods that have been devised in recent years and mentions the work of J. M. Blake described in an article in this Journal in 1915. Moore has worked chiefly with Rochelle salt, but has applied the process successfully also to potassium alum. A saturated solution of Rochelle salt is made up at a convenient, accurately determined temperature, usually between 35 and 40°. The solution is removed from the excess of salt, heated to about 7 or 8° above the saturation temperature, filtered and kept not less than 4 or 5° above that temperature. Small seed crystals are hung in a jar by means of threads or wires fitting into grooves cut around these crystals. Then the salt solution is poured in, the jar is covered with a glass plate and placed in a water bath the temperature of which is about 0·5° above the saturation point of the solution. The temperature is allowed to fall to practically the temperature of saturation as fast as the bath cools off, then by means of a delicate thermometer and a thermostat the temperature is allowed to drop at the rate of about 0·1° per day until the crystals have increased noticeably in size and are perfect in form. This usually takes about one day. Then the temperature is lowered at the rate of 0·2° a day until the crystals are about an inch long, and the rate of cooling is gradually increased to 0·3 to 0·4° and 0·5 to 0·6° as the crystals become larger. The thermostat setting is changed twice a day. When the solution has cooled to about room temperature the crystals are removed and dried by wiping with a soft, dry cloth. The method requires care for the production of perfect crystals, and about a month was required to grow a clear, perfectly developed crystal about 3 inches long. For details reference must be made to the original article.—*Jour. Amer. Chem. Soc.*, **41**, 1060. H. L. W.

3. *Modifications of Pearce's Method for Arsenic.*—The original method of Pearce consists in fusing the substance with sodium carbonate and potassium nitrate, extracting the resulting mass with water, boiling the filtrate with excess of nitric acid, neutralizing exactly with ammonia, precipitating silver arsenate, filtering off the latter, dissolving it in nitric acid, and titrating for silver with a thiocyanate solution. Since the

neutralization with ammonia presents some difficulty from the fact that silver arsenate is soluble both in nitric acid and in ammonia, a modification of the process was proposed by Canby consisting in neutralizing the solution with zinc oxide in place of ammonia. This modification was criticized by Bennett, who found it inexact, and proposed boiling with acetic acid in place of nitric, neutralizing with sodium hydroxide solution in presence of phenolphthalein, and then making the liquid just acid with acetic acid before precipitation with silver nitrate.

Professor John Waddell, of Queen's College, Kingston, Ontario, with the assistance of several students, has found that the neutralization with considerable amounts of zinc oxide may lead to very low, incorrect results, evidently from the formation of zinc arsenate along with the silver arsenate, but he has found that zinc oxide may be used for the neutralization with good results if the acid has been previously almost neutralized so that only a small amount of the oxide is employed after the addition of silver nitrate. He has found, further, that the Bennett modification may give somewhat high results, and he prefers to boil the alkaline solution with nitric acid, to make slightly alkaline with pure caustic soda, and then very slightly acid with acetic acid before precipitating silver arsenate.—*Jour. Indust. and Engr. Chem.*, **11**, 939. H. L. W.

4. *New Fluorescent Screens for Radioscopic Purposes.*—Up to the present time barium platinocyanide has been employed for these screens, but recently their cost has become exorbitant on account of the scarcity and high price of platinum. On account of this inconvenience it has become very desirable to replace the platinum compound with a cheaper substitute. P. Roubertie and A. Nemirovsky have, therefore, introduced a new compound for the purpose. As the result of a long search by one of the authors it was found, as long ago as 1911, that the tungstates of the magnesium group of metals become luminous under the action of the X-rays. They have succeeded in preparing screens with these salts, especially with cadmium tungstate, which gave very satisfactory results. These screens have certain advantages. They are exempt from permanent phosphorescence such as is displayed by certain sulphides which have also been proposed for the purpose. They are unchanged by atmospheric action and do not deteriorate under the action of the X-rays as do the platinocyanide screens, and, further, unlike the latter they give a white luminescence, with black shadows, agreeable to the eye of the observer and also easily photographed.—*Comptes Rendus*, **169**, 233. H. L. W.

5. *Scattering of Light by Solids.*—The earlier investigations by R. J. Strutt on the scattering of light by gases and liquids have been recently extended by the same author to substances in the solid state. The materials studied were various kinds of glass, different varieties of quartz, and Iceland spar.

Numerous specimens of plate glass and optical glass were examined, and all were found to produce scattering. The kinds of glass, however, differed from one another in the intensity and completeness of polarization impressed upon the transmitted light. In the case of Chance's crown glass the intensity of the vibrations parallel to the direction of the primary beam was experimentally determined to be 8 per cent. of the intensity perpendicular to this beam. The corresponding ratio for ordinary plate glass was found to be 3 per cent. Strutt says that "In the case of glasses, the wide difference between different samples suggests that scattering is due in the main to inclusions rather than to the molecules. These inclusions are probably to be regarded as spherical, some of them with a diameter not small compared with the wave-length. In this case the defect of polarisation in glass would be due to the appreciable size of the obstacles, whereas in gases it is due to lack of spherical symmetry."

Yellow quartz and smoky quartz were found to have the property of scattering light very strongly, the coloring matter being evidently distributed in the crystal in the form of small particles analogous to those found in glass. Obviously the scattered light should be analyzed parallel and at right angles to one of the principal planes of the crystal in order to avoid the disturbing influence on the relative intensities which otherwise would arise from double refraction. In the case of a crystal of yellow quartz from Madagascar the polarization of the scattered light was fairly complete, as the weak (parallel) image had only about 0·7 of one per cent. of the intensity of the strong (perpendicular) one. "This is decidedly more perfect polarisation than was obtained with any of the gases examined in the earlier investigation." The stronger image was bluish, while the fainter was a very rich blue. A specimen of slightly smoky quartz from Brazil gave less scattering than the preceding, the intensity of the weak image being about 3 per cent. of that of the strong image. Nevertheless the color was a "good sky-blue." The observations above referred to were made when the axes of the primary beam and of the crystal coincided.

On the other hand, if the line of vision is along the crystallographic axis then the rotatory property of the crystal manifests itself by causing (in white light) the two polarizations to appear to the eye as of equal intensity. The rotatory effect is best shown, however, by using a nicol prism to polarize the incident beam and to allow the cloud of scattering particles to act as analyzer. As the beam advances through the crystal, the plane of polarization is rotated, so that alternations of light and darkness are observed laterally, corresponding to rotations of 90°. The colored bands obtained with white light are very striking, but they rapidly lose their purity after a few periods as a consequence of the superposition of different orders. The

original paper is accompanied by a plate showing photographs of the bands obtained in white, in monochromatic violet, and in filtered yellow light.

With a specimen of quartz, which was apparently quite colorless, it was not possible to observe the scattering visually, but it was detected photographically. Intensity comparisons were made between the total light scattered by clear quartz and by certain other media. The following results were obtained: dust-free air, 1; clear quartz, 8; plate glass, 300; liquid ether, 900. "I have also observed a scattering strong compared with that of air, in a rhomb of clear Iceland spar. No intensity measurements were made."—*Proc. Roy. Soc.*, **95** A, 476, 1919.

H. S. U.

6. *Apparatus for the Direct Determination of Accelerations.*—The question of the determination of the acceleration of the true motion of the ground in various seismic phenomena, or of the motion in different parts of buildings, bridges, and all kinds of artificial structures, due to explosions, shocks, or oscillations of the ground, has a considerable theoretical and practical interest, since the investigation of these accelerations serves as a guide in the study of the mechanical forces by which these movements are caused. An assemblage of apparatus which fulfills all the requirements of the problem has been ingeniously designed and subsequently tested by the late B. GALITZIN. The essential parts of the apparatus, intended for the study of horizontal movements only, will be described in the following sentences. Obviously, the same principles may be applied to the analysis of vertical movements.

The base of the instrument proper consists of a horizontal solid cast-iron platform which supports, and is rigidly attached to, a prismatic mass of the same material. The cross-section of the prism, in the plane of motion of the pendulum to be described below, is a right triangle $ABC$. The short side $BC$ is horizontal and the long leg $CA$ is vertical. At the upper vertex $A$ there juts out horizontally a short rigid projection which supports a massive pendulum in such a manner as to permit free motion only in the plane of the triangular vertical section of the prismatic pillar. The pendulum is of the Borda type with a rigid bar above the heavy bob. A pin is fastened to the bob on the side nearest to $CA$. The axis of this pin passes through the center of mass of the entire pendulum in a direction at right angles to the long axis of the bar. When at rest, the bar makes a small but finite angle $\alpha$ with the vertical, $CA$. Between the face $CA$ of the pillar and the nearer end of the pin, a little table or platform is built out solidly on the pillar. This table supports a plane-parallel slab of quartz suitably cut with respect to the crystallographic axes. The back of the slab makes good contact with a solid wedge of triangular cross-section the upper angle of which is equal to $\alpha$. In other words, the front face of

the slab is parallel to the axis of the bar and hence at right angles to the pin.

Let $M$ denote the mass of the pendulum bob. When the system is at rest the normal "pressure" on the slab is given by $P_0 = Mg \sin \alpha$. When the apparatus is moving with an horizontal acceleration $\ddot{x}$ the pressure is $P = Mg \sin \alpha + M\ddot{x} \cos \alpha$. In order that the pin may always remain in contact with the slab it is necessary to choose the angle $\alpha$ so as to satisfy the inequality $\tan \alpha > w_m / g$, where $w_m$ is the greatest absolute value of the acceleration for the registering of which the apparatus is designed. Since $g$ is relatively large the angle $\alpha$ is usually small. Let $p = P - P_0$, and write $w$ in place of $\ddot{x}$, then $p = Mw \cos \alpha$. "Thus the pressure $p$ is always proportional to the acceleration, quite independently of the form of the function $x = f(t)$."

Accordingly the problem is now reduced to that of finding an experimental arrangement which would make it possible to determine directly the instantaneous value of $p$. The phenomenon of piezo-electricity enables this to be accomplished without difficulty, for, as is now well known, if a plate of quartz or tourmaline be placed between two metallic sheets and subjected to pressure, a free electric charge will appear on the sheets. Moreover, within wide limits, the magnitude of the charge is directly proportional to the pressure. The details of the electric connections are too simple and obvious to merit full description in this place. Suffice it to quote that: "The most suitable instrument for measuring the charge is Luts-Edelmann's string electrometer." The motions of the string are easily recorded photographically by the aid of simple optical accessories. The numerical data and photographic curves given in the original paper are quite consistent with the following conclusions stated by the author:—"The apparatus described above for the direct determination of accelerations proves to satisfy fully the object for which it was designed. It gives directly, without any appreciable retarding effect, the instantaneous value of the acceleration, however arbitrary the type of motion may be. It does not introduce any oscillations of its own, it has very small inertia, and does not manifest any fatigue. Its sensitiveness may be regulated as desired."—*Proc. Roy. Soc.*, **95** A, 492, 1919.

H. S. U.

## II. Geology.

1. *Shore Processes and Shoreline Development;* by Douglas Wilson Johnson. Pp. xvii, 584; 73 pls., 149 text figs. New York, 1919 (John Wiley & Sons).—In this good book is clearly described the cycle of shore processes that develops the various kinds of shorelines along the oceans. The author proceeds logically in his study, from the cause and internal nature of water

waves and current action to the work they do. Then he takes up the terminology and classification of shore types, and this leads into a long account of the development of shorelines. Finally there is a chapter on shore ridges and their significance, and another on the various kinds of shore structures made by the waves, as ripple-marks, etc. The book is easily understood by the careful reader, as each chapter opens with an "advance summary" and closes with a "résumé."

We are told that waves 40 feet high are of fairly frequent occurrence in the open oceans, that a jar brought up from a depth of 220 feet had gravel in it the size of a hazelnut, and that a lobster pot at 180 feet depth had stones washed into it weighing up to one pound. "We may take 600 feet as the limiting depth of ordinary wave disturbance, although Cornish set 900 feet as the limit for the largest recorded waves" (225). Ripple-marks are sometimes made by either waves or currents in fine sand at a depth even greater than 600 feet. A single storm has removed from the Chesil bank in England as much as 4·5 million. tons of shingle, and before it subsided one half of it was moved back again. The great wave-cut platform off Norway has a maximum width of 40 miles.

Wave base is "the imaginary plane down to which wave action tends continually to reduce the lands." Johnson adds that "A cycle of wave erosion ends, therefore, when all the land is reduced to a plane surface about 600 feet below sealevel." It is safe to say that such a completed cycle is rarely, if ever, attained even on the land facing the great oceans, while the inner shallow seas, like Hudson Bay and the Baltic, do not have waves of anywhere near the depth penetration and therefore not of the eroding strength of those of the deep oceans. On the other hand, if the ocean waves are cutting planes whose surface is "about 600 feet below sealevel," the reviewer can not understand why there should be so much material lying upon the continental shelves. Can the explanation be that the eroded material of the land is being delivered upon the deeper parts of the shelves faster than the great waves can carry it seaward? If so, then wave base can not be eroded down to 600 feet of depth in most places. C. S.

2. *World-Power and Evolution;* by ELLSWORTH HUNTINGTON. New Haven, Yale University Press, 1919, 287 pp., 30 text figs.—A most interesting and readable book for biologists, paleontologists, physicians, and statesmen. The underlying thesis is that organic evolution and maximum health are largely conditioned by a favorably changing environment, chiefly climatic. Under favorably cool to even cold seasonable climates, man is energized, and with plenty of food and water he is stimulated to idealism and a higher civilization that is bound to be spread among the less well situated. The book is thought-provoking in its explanation as to why Germany is so dominant in action, why

the great Roman Empire fell, what was the cause of the Dark Ages, and why the diabolical government of modern Turkey exists. A favorable climate produces the greatest number of healthy beings, and an unfavorable one, a nation of laggards, more or less sick and helpless. C. S.

3. *Brachiopoda of the Australasian Antarctic Expedition,* 1911-1914; by J. ALLAN THOMSON. Scientific Reports of the Expedition, Ser. C.—Zoology and Botany, vol. 4, pt. 3, 76 pp., 4 pls., 1 map, 1918.—To state that this excellent work on recent brachiopods treats of the new genera *Amphithyris, Gyrothyris,* and *Stethothyris,* and of fifteen species of which nine are new, is only to mention the groundwork that leads to biologic and paleogeographic generalizations of a wide scope. The living material described here from the Antarctic coast-line, Macquarie Islands, and Tasmania, is also considered in the light of the Tertiary brachiopods of the southern hemisphere. The author furthermore points out that in all probability the family Terebratellidae will have to be again subdivided.

As the larvae of most brachiopods (all Articulata) are without a mouth and must settle to the sea-bottom in probably not more than twelve days if they are to feed and live, their development prevents the young from crossing from one continent to another. Therefore cases of discontinuous distribution appear to have a profound significance and help to decipher former shallow-water areas or lands that are now either completely sunken into the deeps, or to indicate lands that are now more or less fragmented. In this way, Blochmann and Schuchert have shown, on the basis of living brachiopod distribution, the former presence of ancient Gondwana.

The reviewer in 1911 thought that the habitats and the bathymetric and geographic range of living brachiopods were fairly well established for all regions north of the equator, but that a great deal more would be learned about those of the Antarctic seas. It now seems that he did not fully realize the many new facts that would so soon come to light about the austral representatives. Thomson points out that these southern oceans have long been generating centers for peculiar genera and species, and that not only did boreal forms pass into the southern hemisphere, but that even "northern forms originated in the south. Yet the southern Tertiary faunas were at least as rich and varied as those of the north." The author is hopeful that "When all the Recent and Tertiary species of the southern hemisphere have been correctly placed genetically, it may be possible by the aid of brachiopods alone to gain a fairly accurate idea of the latest former land connections of the southern hemisphere" (53).

The paper under review is accompanied by a very valuable new bathymetric map of the Antarctic and Southern oceans, which includes all of the latest soundings and in which the shad-

ing is so designed as to throw into relief the areas of the sea-bottoms above 1000 fathoms. This map will be of much value to paleogeographers. Even though Thomson realizes that the map is not yet nearly final, it leads him to recognize nineteen separate and distinct geographic districts with their marine faunas. Each one of these districts has from one to twenty-seven species, and ten of them have living brachiopods. The others are wholly devoid of them. The latter appear to be as a rule oceanic or volcanic islands, though it is curious that a great continental mass like Madagascar should be devoid of living brachiopods.

Thomson says that the greatest future scientific increase of brachiopod distribution is to be gleaned rather from a survey of the "little known submarine banks of the Southern and the Pacific ocean bottoms than from a further Antarctic expedition. If these banks have arisen by subsidence of previous lands, remains of coastal faunas such as brachiopods are to be expected. If, on the other hand, they represent recent diastrophic uplifts of formerly deeper portions of the ocean floor, no such faunas can occur. . . There is thus a practical method of testing the theory of the permanence of ocean basins" (42).

Thomson finds that the present distribution of austral living brachiopods has not changed much in the larger geographic sense since the Miocene. They owe their present distribution to a more ancient time when means of intercommunication between the lands bordering the South Pacific Ocean was better than at present. The times of these former land connections seemingly were in "the late Jurassic or early Cretaceous and in the late Pliocene and post-Tertiary, but not in the Oligocene-Miocene" (6). C. S.

4. *Pelecypoda of the St. Maurice and Claiborne stages;* by G. D. Harris. Bull. Amer. Pal., No. 31, 1919, 268 pp., 60 pls.—Professor Harris has now been collecting and studying the Eocene Mollusca since 1892, and in this volume he describes the bivalves of the two stages beneath the top one, the Jackson stage. The work is dedicated to the statesman and paleontologist, Truman H. Aldrich, who is the connecting link between the first paleontologist to describe Claiborne shells, Timothy A. Conrad, and the workers of the present.

In the present work are described about 85 established genera and 255 recognized species and varieties. The author, however, had to study about 613 forms, the difference being due to synonyms or erroneous generic references. There are but two new genera, *Mauricia* and *Pachecoa*, and of new species and varieties there are 57. The author is to be congratulated upon his persistence in doing so much good in making known the early Tertiary Mollusca, especially as he has done this without much help from any one, even in the illustrating and printing of his publications. C. S.

5. *Tertiary mammalian faunas of the Mohave Desert;* by JOHN C. MERRIAM. Bull. Dept. Geology, Univ. of California, vol. **11,** No. 5, pp. 437a-e, 438-585, 253 text figs., 1919.—This paper is of considerable interest to mammalian paleontologists and to students of West Coast Tertiary history. The bulletin contains some of the results of researches made by its author during the past eight years into the animal life of the Tertiary in the southwestern part of the Great Basin. The upper Miocene is represented by an assemblage of mammalian fossils containing approximately 26 species. The material is derived from the Barstow formation, which is exposed over an area measuring several miles in diameter in the eastern part of the Mohave Desert, southern California, about 75 miles northeast of Los Angeles. The lower Pliocene is known from a fossil fauna of approximately the same number of species collected from the Ricardo formation, the badland exposures of which are situated 60 miles to the west of the Barstow locality, at the northwestern edge of the desert along the base of the Sierra Nevada. The Barstow and Ricardo formations are nowhere known to be in contact.

The fossil materials on which the study is based are stated by Dr. Merriam to be largely fragmentary, connected parts of skeletons being rare. The materials were secured through rather thorough collecting from the two areas of exposures, the size of both of which is relatively small as compared with the extensive areas of fossil-bearing badlands in the Great Plains. Several species of horses are the most significant forms in both faunas and their remains constitute the bulk of the well-preserved material. Several species of dogs and of camels, and an oreodont are also represented in both faunas. There are described from the Miocene horizon a new species of oreodont and a new variety of horse, and from the Pliocene horizon three new carnivores and a new oreodont.

The Miocene Barstow fauna has its nearest correlative in the Great Basin in the Cedar Mountain fauna of southwestern Nevada; in the Rocky Mountains and Great Plains regions it seems to have been contemporaneous with the fauna from the Sante Fe beds of New Mexico and probably in part with the Snake Creek of western Nebraska. The Pliocene Ricardo fauna is shown to be approximately equivalent to three mammal-bearing formations of the California Coast Ranges, thereby contributing to a fuller understanding of the relation in time between the deposition of Pacific Coast marine and interior nonmarine formations. The Ricardo has no exact correlative in the Great Basin, being older than the Rattlesnake and Thousand Creek formations. It is near the Blanco of Texas, Snake Creek of Nebraska, Republican River of Kansas and the Alachua of Florida.

The evidence yielded by the faunas and by the deposits indi-

cates that in upper Miocene and lower Pliocene times the climate and relief of the Mohave region were comparable to those of to-day but the aridity was probably somewhat less.

The paper is a distinct contribution to Tertiary history and mammalian paleontology. J. P. B.

### III. Miscellaneous Scientific Intelligence.

1. *Thirteenth Annual Report of the President,* Henry S. Pritchett, *and the Treasurer,* Robert A. Franks, *of the Carnegie Foundation for the Advancement of Teaching.* Pp. vi, 162, New York City (576 Fifth Avenue).—The annual report of the Carnegie Foundation, distributed some little time since, is particularly interesting because it gives a full statement of the new contributory plan of pensions which has been finally adopted and is known as the "Teachers Insurance and Annuity Association of America." The progress of pension work, particularly in this country, is also discussed in detail, and the plan recently adopted by one of the largest corporations in the country, is severely criticized. It is interesting to note that: "the permanent endowments of the Carnegie Foundation of sixteen and a quarter million dollars have been approximately doubled by the setting aside of one million dollars of accumulated surplus and the receipt of eleven million dollars in new funds to be used in terminating the old pension system of the Foundation, and two million dollars for the inauguration of a new plan. The Foundation has distributed six and a half million dollars for pensions for professors and their widows under the old plan, and has provided for the distribution of sixty million dollars for the retirement of the six thousand teachers who were in the associated institutions in 1915."

Bulletin No. 13 of the Foundation (pp. xiv, 271), is entitled *Justice and the Poor,* and has been prepared by Mr. Reginald Heber Smith. It gives a large amount of information as to existing conditions with statistics of local aid work and definite proposals for reform. It is hardly necessary to add that perhaps no other matter now before the public mind is more important than this subject of doing justice to those of very limited means.

The official circular sets forth concisely the particulars as to injustice done and remedies proposed. It ascribes the existing denial of justice to the poor to the great underlying social and economic changes of the last half century, to which our judicial system failed to adapt itself.

The defects in our judicial system which prevent the poor from obtaining evenhanded justice are: First, the delay arising from antiquated court organization and overcomplex procedure. Second, the expenses that the state itself levies in the form of court costs and fees. The third inherent difficulty is the expense of lawyers' services. For the orderly presentation of cases in

court lawyers are essential; yet millions of persons need just such assistance from time to time but can not get it because they are too poor to pay for it. The report argues, that if one party is too poor to buy lawyers' services they must somehow be furnished him unless miscarriage of justice is to be the portion of the poor, the weak and the ignorant. It is also recognized that in certain types of cases attorneys may be dispensed with as in the small claims courts, such as now exist in Cleveland and Chicago.

In general, the definite solutions advocated are the legal aid organizations for civil cases and organizations similar to the public defenders for criminal cases. There are now forty-one such organizations, operating in some cities as private charities, in others as public bureaus. Already they have given legal aid to one and a half million clients and through their work have secured for clients sums owed amounting to four million dollars.

2. *Publications of the Carnegie Institution of Washington*, ROBERT S. WOODWARD, President.—Recent publications of the Carnegie Institution are noted in the following list (continued from vol. **48**, pp. 163, 164):

No. 248. The Cactaceæ. Descriptions and illustrations of plants of the Cactus Family; by N. L. BRITTON and J. N. ROSE. Volume I, quarto; pp. vii, 236; 36 plates in part colored and 302 text figures.

No. 256. History of the theory of numbers. Volume I: Divisibility and Primality, by LEONARD EUGENE DICKSON. Pp. xiii, 486.

No. 257. I. Orthogenetic evolution in Pigeons. Posthumous Works of C. O. WHITMAN; Edited by OSCAR RIDDLE. Vol. I, quarto. Pp. x, 194; 88 plates, 36 text figures.

No. 257. II. Inheritance, fertility, and the dominance of sex and color in hybrids of wild species of Pigeons. Posthumous Works of C. O. WHITMAN; edited by OSCAR RIDDLE. Volume II, quarto. Pp. xx, 224; 39 plates, 11 text figures.

No. 257. III. The behavior of Pigeons. Posthumous Works of C. O. WHITMAN. Volume III, edited by HARVEY A. CARR, with a preface by OSCAR RIDDLE, quarto. Pp. xi, 161.

No. 263. The mechanism of evolution in Leptinotarsa; by WILLIAM LAWRENCE TOWER; including appendix on the relation of water to the behavior of the potato beetle in a desert; by J. K. BREITENBACHER. Pp. viii, 384; with plates, maps and text figures.

No. 279. A biometric study of basal metabolism in man; by J. ARTHUR HARRIS and FRANCIS G. BENEDICT. Pp. vi, 266.

No. 280. Human vitality and efficiency under prolonged restricted diet; by FRANCIS G. BENEDICT, WALTER R. MILES, PAUL ROTH, and H. MONMOUTH SMITH. Pp. xi, 701, with frontispiece and 124 text figures.

No. 285. The genetic and the operative evidence relating to

secondary sexual characters; by T. H. MORGAN. Pp. 108, 10 plates.

No. 286. The ecological relations of roots; by JOHN E. WEAVER. Pp. vii, 128; 33 plates, 58 text figures.

No. 287. The carbohydrate economy of Cacti; by HERMAN AUGUSTUS SPOEHR. Pp. 79.

No. 288. Studies of heredity in rabbits, rats, and mice; by W. E. CASTLE. Pp. 56, 3 plates, 5 text figures.

3. *National Academy of Sciences.*—The autumn meeting of the National Academy will be held in New Haven, Connecticut, on November 10-12. The local committee consists of Professors Bumstead, Mendel and Harrison.

4. *The Birds of North and Middle America;* by ROBERT RIDGWAY—Part VIII. Bulletin No. 50 of the U. S. National Museum.—This volume of 852 pages, accompanied by 34 plates, is the eighth in the important work undertaken by Mr. Ridgway. Without attempting to give the names of all the families represented, it may be sufficient to say that those represented include chiefly the birds prominent on our seacoast. Part IX is now in course of preparation and, as the effects of the war conditions are no longer so serious, its appearance may be expected at no distant date.

5. *Biographical notice of Joseph Barrell.*—Through an oversight, the name of PROFESSOR CHARLES SCHUCHERT was omitted as the author of the notice of Professor Joseph Barrell in the October number, pp. 251-280.

## OBITUARY.

FREDERICK BRAUN, the oldest American dealer in fossils and minerals, died at Brooklyn, New York, on November 12, 1918. He was born on April 29, 1841, at Nordhausen, Germany, and in 1861 emigrated to Chicago, where he worked as a carpenter. Later he settled at Cincinnati, and here he was employed for a time by Mr. Paul More, a merchant, to gather fossils for him. At Crawfordsville, Indiana, he opened the first quarry for the famous Keokuk crinoids, and his well-cleaned material is now scattered in the museums of America and Europe. In 1889 he removed to New York City, and later to Brooklyn. He was often employed by individuals and museums to make collections of fossils, or to arrange and label their material. He was an indefatigable collector, willing to go anywhere, under the most trying of conditions, and his results were always good. He was, however, an independent character who would do things only in his own way, and for this reason he never reaped the reward that might and should have been his. The finest specimens he laid away for his private collection, always hoping to sell it intact to some institution as the Fred Braun Collection. No one, however, was able to purchase it in his time, but it is to be hoped that the collection will be acquired by one of our larger museums.

# Old-time Pennsylvania Amethysts

Our recent purchase of the

**Mineral Collection of the late Michael Bradley**

of Chester, Pennsylvania, has brought to Rochester 130 crystals of Amethyst from Delaware County and Chester County, Pennsylvania, found 25 to 30 years ago.

Mr. Bradley lived close to the localities and watched up the finds more closely than any other collector and secured many of the very finest. The best of them were sold many years ago and one specimen is reported to have brought $200. Those we now have are by far the best on sale during the past twenty years.

The color usually does not pervade the whole crystal, but is concentrated near the tips into an intense purple of great beauty. A few of the best crystals would yield gems of unexcelled beauty.

Multitudes of minute crystals of Rutile (?), often but not invariably at right angles to and near the crystal faces, are revealed by a lens.

The crystals are stout-prismatic in habit, frequently doubly terminated and average from $1\frac{1}{2}$ to 3 inches in length and $1.00 to $10.00 in price. There are some very choice crystals $\frac{5}{8}$ to 1 inch long at $1.00 to $1.50 each; other small crystals, not so good, 10 to 50 cents.

One group of rather pale crystals in parallel position, about 4 x 6 inches, $10.00, another 5 x $8\frac{1}{2}$ inches, $10.00.

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The Bradley collection embraces about 2000 specimens, many of them choice—such things as Dioptase, Emerald, Tyrolese Epidote, Wulfenite. We will gladly send an assortment on approval.

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## WARD'S NATURAL SCIENCE ESTABLISHMENT

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THE

# AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

## Art. XXVII.—*The Middle Ordovician of Central and South Central Pennsylvania;* by Richard M. Field.

### Introduction.

The geographic position, as well as the faunal and lithological peculiarities of the Ordovician formations of central and south-central Pennsylvania, make it possible to treat their area, for descriptive purposes, as a part of a province within the Ordovician terranes of eastern North America. The sketch-map (fig. 1), copied from the atlas of the Second Geological Survey of Pennsylvania (1),[1] gives an approximate idea of the location and distribution of the formations which are exposed in eroded anticlinal valleys parallel to the northeast and southwest axis of the Appalachians. The map shows all of the formations from the Beekmantown to the Eden, no attempt having been made to plot the exact areal distribution of the Middle Ordovician formations alone. At the time of the Second Geological Survey, all of the limestone above the Upper Cambrian and below the Upper Ordovician was represented by a single color, and called the "Valley limestone." The white numbers on the black areas of the sketch-map refer to the principal sections in the Middle Ordovician which have been studied by the writer and which will be described in detail elsewhere.

The large western area exposed in Bedford, Blair, Center, Clinton and Lycoming Counties contains approximately 840 square miles, the northeastern section at Salona being 105 miles from the Willow Grove section to the northwest. In Center County the Ordovician lime-

[1] Reference numbers in parentheses in the text apply to the bibliography at the end of the article.

stones are separated by the Silurian sandstone of Nittany Mountain into the areas roughly represented by Nittany Valley to the west and Penns Valley to the east. The large eastern terrane located in the rich and beautiful canoe-shaped valley of the Kishacoquillas in Mifflin and Huntingdon counties has an approximate area of 140 square miles.

Fig. 1.


**Fig. 1.—Map of Central and South Central Pennsylvania.**

**The black areas show the distribution of the Ordovician formations in the province. The numbers refer to the locations of the sections as follows:—1. Coburn. 2. Millheim. 3. Spring Mills. 4. Salona. 5. Bellefonte. 6. Tyrone. 7. Franklinville. 8. Roaring Spring. 9. Loysburg. 10. Thorpes Quarry-Willow Grove. 11. Lemont. 12. Center Hill. 13. Reedsville. 14. Belleville. 15. Nagìney.. 16. Chambersburg.**

Complete and well-exposed sections are not numerous within any of the areas, but fortunately the development of quarries along the strike of the purest beds of limestone, which extend through the towns of Tyrone, Bellefonte and Salona, exposes the zones above and below this horizon. The older quarries, where weathering has gone on for some time, furnish the best general collecting ground for fossils. Well exposed sections of the lower Middle Ordovician are to be found in the abandoned road metal quarries of the region. Unfortunately, however, most of the above mentioned sections lie close to the Alleghany Plateau under which the Ordovician limestones of Pennsylvania dip.

To the southeast of the central Pennsylvanian province lies a more or less parallel band of somewhat metamorphosed Ordovician limestones and dolomites which extends through Carlisle, Easton and Port Jervis. The southwestern extension of the easterly belt, on the other hand, the formations of which are metamorphosed, passes through Chambersburg and continues as far as Birmingham, Alabama. Thus the central Pennsylvanian province is the most western extension of the Ordovician formations of the state, and it will also be seen that this province occupies a middle and somewhat isolated position within the Ordovician terranes of eastern North America.

## History.

The earliest reference to the Ordovician of central Pennsylvania appears to be that of Richard C. Taylor (2), who in 1835 noted the fossiliferous beds at the foot of Jacks Mountain. Then there is no mention of it until the publication in 1858 of the First Geological Survey of Pennsylvania by H. D. Rogers (3). In this work, on an excellent colored geological map which is supposed to have been compiled by the Survey but which was probably largely copied from an earlier map of Dr. Henderson's, the Ordovician formations are shown in light-blue and green.

The geological map of the Second Survey (4) shows little or no advance over the first, the Lower and Middle Ordovician formations being still undifferentiated and shown in light blue. The county reports, however, contain many references to Middle Ordovician outcrops and

sections, though several of the sections in the present paper are not mentioned in them.

In brief summation, then, of the work on the Middle Ordovician limestones of central and south-central Pennsylvania during the state surveys, it may be truthfully said that Rogers gave a remarkably full and accurate description of the faunas, for his time, but that the Second Survey added very little to what was already known. Hall and Simpson were the chief cataloguers of fossils during this period, but even they did little or nothing to elucidate the Ordovician faunas of central Pennsylvania. To Simpson, however, must be given the credit for the discovery and description of the new and curious trilobite *Homalonotus* (*Brongiartielli*) *trentonensis*.

In 1903, Collie (5), in his paper on the Bellefonte section, gave the first detailed and correlative description of the Middle Ordovician limestones and faunas, in part as follows:

> "There is apparently no true Chazy present, but rocks containing the fauna of the Stones River Group, which includes the Birdseye zone of New York as its upper member, follow immediately on the Beekmantown. These in turn are followed by the Black River and Trenton Groups, above which follow in order the Utica and Lorraine shales."

Collie gives a detailed description of the Trenton, which he divides into eight fossiliferous zones, but he does not appear to appreciate the difference in fauna and lithology between the lower and upper limestones. His faunal list for the Trenton of the Bellefonte section is, as a whole, remarkably complete and the writer has been able to add only a few species, but his list of the Stones River species is incomplete, as he failed to report many of the thoroughly critical and distinctive types contained in this formation.

The following year Grabau (6) commented upon Collie's upper Beekmantown as follows:

> "Since the fossiliferous horizon below the 2335 feet of unfossiliferous(?) beds is upper Beekmantown and the first fossiliferous horizon is Upper Stones River (Upper Chazy), the lower Stones River, or Chazy proper, seems to be represented by this unfossiliferous(?) horizon. If, then, this series is taken from the Beekmantown and added to the Chazy, we have 2500 feet ($\pm$) of the latter, a division which agrees more fully with the

Arbuckle Mountain section. Comparing with this the Mohawk River section, 250 miles to the north, we find a striking discrepancy. In the Mohawk section less than 500 feet of Beekmantown rest with a basal conglomerate upon the Adirondack gneisses, and is followed after an erosion interval by at the most 30 feet of Lowville (Upper Stones River or Upper Chazy). This is conformably succeeded by the Black River and Trenton limestones.''

In 1910 Ulrich (7) discusses the Lower Ordovician (Canadian) limestones and dolomites of the Bellefonte section but writes nothing regarding the Middle Ordovician series. In his correlation tables (op. cit., p. 27) he lists the following formations:—Trenton (Reedsville; Lower Trenton). Black River (Amsterdam; Lowville). Stones River (Pamelia).

In an ''Outline of Practicum Work in General Geology,'' which Prof. E. S. Moore has privately printed for his class in Geology at Pennsylvania State College, the Middle Ordovician is divided in the following manner:

''Trenton, highly fossiliferous thin-bedded limestone and black to brown shale, 791 feet. Black River: This group includes the Black River and Lowville limestones which are usually pure, blue to grey rocks. Thè Lowville contains the famous quarry-rock, 182 feet. Stones River, bluish limestone, 260 feet.''

A still more recent paper is that by Professor Raymond (8) in which he says:

''At Bellefonte, Penn. according to the observations made by Mr. Richard M. Field and the writer, a zone of dark limestone, containing such typical Leray (Black River) species as *Columnaria halli*(?) and *Maclurites logani,* is followed by more argillaceous limestone containing *Echinosphærites* and a large number of other fossils. Christiania has not yet been found in the Bellefonte section, but this section does definitely show that the *Echinosphærites* zone is there younger than the Leray-Black River of New York. As shown by Mr. Field, there is essential agreement between the section at Bellefonte and that at Chambersburg and Strasburg, so that all three of these occurrences of Echinosphærites may be dated definitely as post-Leray.''

The preceding were the latest data which had been published on the Middle Ordovician of central Pennsylvania at the time that the writer finished his field work in this region. The Bellefonte section has, however, been visited by many geologists and paleontologists, including members of the state and federal surveys, and

until quite recently it was the only section within the region which had been described in detail.

A description of the section at Roaring Spring was published by Butts (9) in 1916. To the Echinosphærites zone he gave the name Rodman, and divided the subjacent Stones River into two formations, Lowville and Carlim, the latter a new term proposed for the fossiliferous but less pure limestone below the pure quarry-rock. He also proposed the term Lemont for the upper and less pure part of the Carlim. The facts derived from my study of the section at Roaring Spring do not agree in certain important particulars with Butts' published account; his faunal list is also incomplete and contains certain supposedly characteristic fossils which are only to be found 60 to 90 miles to the northeast. Finally, a study of the Roaring Spring and Bellefonte sections alone can give no adequate idea as to the paleogeography of the area, or its relation to the Ordovician terranes of eastern North America.

## Description and Correlation of Sections.

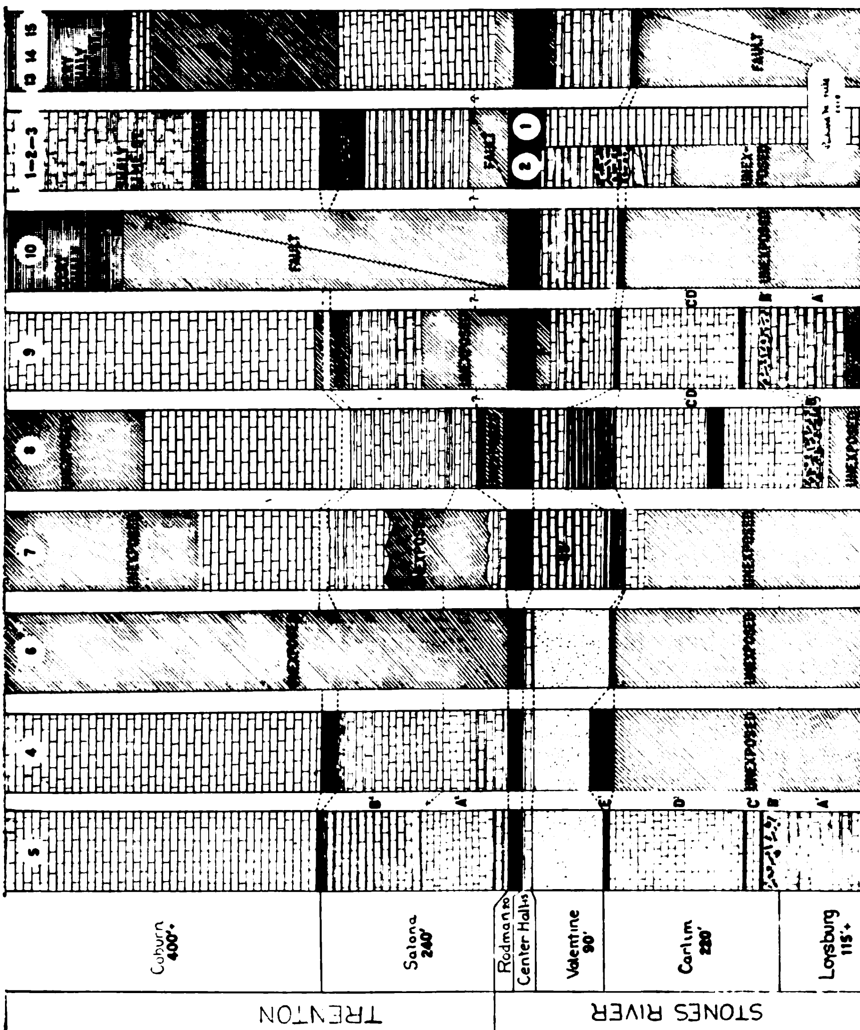
Nine stratigraphic columns are arranged on fig. 2 so as to give a diagrammatic view of the thicknesses and relative positions of the formations, the geographic position of each section being shown by the same number on the sketch-map, fig. 1. These two illustrations, together with the following lithological and faunal descriptions of the formations, will be used in the discussion of the correlation of the sections within the given province. Space does not permit me to give here the complete list of the fauna, which is to be published later, and only those species are mentioned below which are essential horizon markers. The subject in its broadest sense is the paleogeography of central Pennsylvania during Middle Ordovician time.

The formations have been grouped under two main divisions. This has been done for several reasons, it being necessary at present only to draw attention to the fact that the lithology and faunal characteristics of the Salona and Coburn are decidedly different from those of the subjacent Rodman, Center Hall, Valentine, Carlim and Loysburg. The Bellefonte column (No. 5) is placed first because it contains all of the formations from the Loysburg to the Coburn, inclusive. The succeeding

columns are arranged to best illustrate the paleogeography of the province, starting with the Tyrone, Belle-

**Fig. 2.—The Middle Ordovician sections of central and south-central Pennsylvania.**

**The columns are numbered according to the locality numbers on Plate 1. For description of the symbols see the adjacent page.**




fonte, and Salona sections (Nos. 4, 5, 6), and extending to the east as far as Reedsville (No. 13). The field evidence suggesting this arrangement will be taken up under the

discussion of each formation in order. The numbers in the left hand column refer only to the thicknesses of the formations in the Bellefonte section. All of the solid black bars below the Valentine designate Tetradium beds, and the Rodman is also shown by a solid black bar. The solid black bar at the base of the Coburn indicates the Parastrophia zone. Particular horizons are marked by letters, the Stones River series being $A^1$, $B^1$, $C^1$, etc., the Trenton series $A^2$, $B^2$, etc. Intraformational structures are shown by the pattern as illustrated in $B^1$.

*Loysburg Formation.*—The dark and impure, dolomitic limestone which lies between the Beekmantown and the first intraformational zone has been named Loysburg, after the town by that name in the northern part of Bedford county. Collie does not appear to have recognized the existence of this formation, for in his description of the section at Bellefonte he makes no distinction between the lithology and faunal characteristics of the lower and upper Stones River. Butts also does not mention the lowest division of the Stones River group, probably because it is poorly exposed in the section at Roaring Spring. The Loysburg differs from the superjacent Carlim not only in lithology and paucity of fossils but also in the total absence of the reef-building organisms so characteristic of the latter formation. Only the upper 115 feet are exposed at Bellefonte and the base can not be located with any degree of accuracy. The only other section in which it is well exposed is at Loysburg, where it appears to be somewhat less thick.

*Carlim Formation.*—The contact between the Loysburg and the Carlim is well exposed in the section at Loysburg, where the line appears to be quite sharp between the dark, impure and the light-colored purer limestone. There is no evidence of an interformational conglomerate at the base of the Carlim, but wherever the base of this has been observed it is characterized by strongly marked intraformational structures, which at first sight suggest a fine-textured basal conglomerate. These structures are the most striking characteristics of the Stones River group and the writer has been able to trace them from New York to Tennessee. It is obvious that the elucidation of these phenomena is intimately connected with the study of disconformities and no discussion of the correlation of the lower Middle Ordovi-

cian formations is complete without their consideration. In 1916 I published a preliminary paper (10) in which an attempt was made to distinguish between interformational and intraformational structures, especially in limestone and dolomite, as follows:

"A review of the literature, as well as of certain examples in the field, has shown that not all intraformational conglomerates are made up of water-worn materials: in fact, certain of them are composed of distinctly brecciated fragments which show no signs of attrition by water transportation, a common characteristic according to most geologists. It may seem strange at first to consider a 'sun-cracked' limestone as a brecciated rock, and yet viewed in cross-section, or at right angles to the bedding plane, the hand specimen or field section will often show a characteristic brecciated structure.

"It is, therefore, proposed to introduce two new terms, *Glomerate* and *Phenoclast,* in describing all those rocks (glomerates) which are of sedimentary origin, coarse, or psephitic in texture, whether or not their "show" constituents (phenoclasts) give signs of attrition and transportation." "*Glomerate,* according to the Century Dictionary, means 'collected into a spherical form or mass.' It is an old English word and rarely used. Conglomerate in its ordinary sense is also defined as 'a rock made up of the *rounded* and *water-worn* debris of previously existing rocks, etc,' (the italics are the writer's). It is proposed to use the term glomerate in a geological sense to mean any sedimentary or clastic rock made up of roughly graded debris formed within itself or from pre-existing rocks. Such a term would cover breccias, conglomerates and certain other rocks of doubtful origin.

"Nauman, in his 'Geognosie,' proposed the term Psephite, but it has never been widely accepted, and probably never will be although it is a useful word in petrology."

"There is as great a need for a term to express the order or size of the constituents in a sedimentary rock as there is for the term phenocryst, which designates a large crystal in the groundmass of a crystalline rock. *Phenoclast,* from pheno, show, and clast, clastic, broken piece or fragment, is proposed to designate the larger fragments which are easily distinguished from the ground-mass or cementing material. They, the phenoclasts, may be of several orders of size and shape. The term is convenient as it is not always correct to refer to the major constituents of a conglomerate as pebbles, or even brecciated fragments. For instance, in the edgewise glomerates the pebbles and cement are apt to be formed from the same material. Also the shape of the 'pebbles' is hardly pebble-like, neither are the 'pebbles' true brecciated fragments. Their outline is as peculiar and

distinct as is their mode of origin and it is upon the discovery of their origin that the solution of the problem depends. One has but to glimpse at the literature on the subject in order to appreciate the necessity for a reasonably accurate nomenclature."

The lowest bed of the Carlim was laid upon a consolidated surface. There is no evidence of a basal conglomerate, but the presence of ripple-marks and sun-cracks is conclusive proof that the pure calcareous oozes of the Carlim were deposited under alternating conditions of quiet and agitation. If these basal Carlim sediments had been deposited upon the unlithified Loysburg sediments and under the conditions of agitation which have just been cited, we should expect to find an intimate mixture of the two types near the base of the former; such, however, does not prove to be the case. The distinctly banded character of these rocks, together with the frequent zones of ripple-marked, sun-cracked and glomeratic limestone, are particularly suggestive of shallow-water and tidal conditions. The intraformational glomerates represented by $B^1$ on fig. 2 are well exposed in the sections at Bellefonte, Roaring Spring, and Loysburg, but in the former section there does not appear to have been much bottom agitation and the glomerate is either the direct or indirect result of organic activity. The Carlim here begins almost immediately with numerous thin beds of Tetradium, and the growth as well as the destruction of this peculiar and little understood organism has functioned to an important degree in the formation of a typical bioglomerate. The evidence presented in this section indicates that at times conditions were quiet enough for the growth of a thin veneer of the colonial organism, *Tetradium syringoporoides,* but that sometimes the bottom was sufficiently agitated to break up the colony, together with the cementing muds, and deposit the whole material in the form of a fine-textured, intraformational conglomerate in which are also found the remains of other attached and vagrant benthonic species. In the section at Loysburg there are first a few inches of light-colored, banded limestone, then a thick zone of mud-cracked, ripple-marked limestone and glomerate beds which alternate with thin zones of *T. syringoporoides.* The ripple-mark is quite even, with an amplitude of not more than 1 to 2 inches; moreover, it is decidedly symmetrical and appears to belong to the

oscillation rather than the current type. The nature of the ripple-mark, together with the thin mud-cracked layers and associated edgewise glomerates, all indicate that the lower 30 feet of the Carlim were deposited in relatively shallow water and that at times the beds of ooze were exposed to the direct action of the sun and air, the edgewise glomerates being probably formed by the rising of the tide upon the previously mud-cracked flat. The presence of only a few Tetradia-bearing beds in the lower Carlim, and the fact that they become increasingly abundant toward the top of the formation show either that the water was becoming slightly deeper, causing the bottom to become less agitated, or, that the Tetradia were gaining firmer hold upon the low-lying platform and gradually creating a broad-bedded reef more and more resistant to the waves. It appears as if the latter possibility were more in accord with the field data than the former.

In the section at Bellefonte, the middle and most of the upper Carlim, except for the final 10 feet, contain very few Tetradia, but Bryozoa are abundant and appear to have formed a sea-mat upon which a rich fauna of trilobites flourished.

In the upper Carlim of the section at Loysburg, both Girvanella and Tetradia occur in solid beds, giving this part of the formation a decidedly "reef" aspect. Mention should also be made of the occurrence of the compound coral, Columnaria sp.? (closely related to *C. halli*), which is found associated with *Maclurites logani* just below the Beatricea zone. This coral has been found only in the sections from Center Hall to the west. In the section between Center Hall and Reedsville it is particularly abundant, heads from 2 to 3 feet across being closely packed together in their original position of growth; in fact, at this particular spot one would have no difficulty in believing that he was looking at a fossil coral reef. Columnaria is not, however, particularly abundant in the other sections, and was not found at all at Roaring Spring and Loysburg. The Carlim varies considerably throughout the area, but in all sections it is particularly characterized by the presence of such colonial and gregarious organisms as Tetradia, Bryozoa, and Girvanella. That these variations are dependent upon geographic position will be more clearly

brought out after considering the conditions under which the superjacent formations were laid down.

The Carlim is closed with a zone (E′) of shaly, impure limestone, which is well shown in the foot-walls of all the quarries. This zone is somewhat variable in thickness and has been traced from Salona to Tyrone, a distance of over 90 miles. It contains a regular mat of *Tetradium fibratum* and *Beatricea gracilis?* The upper layer which forms the parting plane between the Carlim and the Valentine was particularly well exposed in the Bellefonte quarries in 1917, where approximately one-quarter of an acre of ripple-marked and mud-cracked limestone was displayed on the steep foot-wall of the largest quarry.

*Valentine Formation.*—I have named the pure quarry-rock, which follows the Carlim, from a small hamlet and forge near Bellefonte which are not shown on the county map. The Valentine family was prominent in the early mining industry of central Pennsylvania, and it seems fitting that this valuable bed of limestone should receive its name.

Collie makes no distinction between the pure quarry-rock and the overlying fossiliferous formations, all of which he has grouped under the rather indefinite term of "Black River."

The Valentine does not occur in the section at Roaring Spring, although Butts intimates that this section is identical with those on the Tyrone-Salona line. The contact of this unfossiliferous formation with the underlying Tetradia and Beatricea beds is sharp and clean-cut, but its upper beds merge almost imperceptibly into the superjacent Center Hall. The field relationships of the Valentine will be discussed more fully after the descriptions of the Center Hall. It is simply stated here that this formation occurs as a lens in the upper Stones River beds and is gradually replaced by them to the east.

An examination of the thin section of the Valentine limestone shows that the ground-mass is made up of minute crystals and granular particles of calcium carbonate, which are barely distinguishable under a magnification of 380 diameters. There is no evidence of stratification except under high powers. Throughout the ground-mass are scattered larger grains of calcite, some of which are large enough to be seen macroscopically.

A few scattered particles of the tests of trilobites are

present but they are exceedingly rare and their worn and comminuted appearance suggests that they have been carried some distance. In the finer portions of the ground-mass the grains of calcium carbonate are somewhat obscured by a thin brown film which has the appearance of being either iron-oxide or carbonaceous material. It is interesting to note that, aside from speculations upon this "brown film," there is no evidence which would lead one to suppose that the pure limestone of the quarry beds had been formed by organic agencies.

The following analysis of the quarry-rock shows the total amount of variation which has been encountered in several hundred samples taken during the quarry operations of the last few years and collected along the quarry line from Bellefonte to Tyrone:

| | | |
|---|---|---|
| $SiO_2$ | 0·62% | 0·94% |
| $(Al, Fe)_2O_3$ | 0·32 | 0·40 |
| $CaCO_3$ | 97·81 | 97·60 |
| $MgCO_3$ | 1·27 | 1·06 |

The Valentine limestone is so low in silica that it cannot be used for cement. Its purity makes it extremely valuable for chemical purposes, little or none of it being used for flux or the manufacturing of structural materials. It is interesting to consider the analysis given by Vaughan (12) for the finely divided calcareous muds occurring in the Marquesas and Bahamas lagoons:

| | Bottom sample, east side Marquesas lagoon, Florida | Bottom sample one mile west of west end of South Bight, Bahamas |
|---|---|---|
| $SiO_2$ | 1·18% | 0·29% |
| $(Al, Fe)_2O_3$ | 0·37 | 0·15 |
| $MgCO_3$ | 2·88 | 2·72 |
| $CaCO_3$ | 95·57 | 96·84 |

Vaughan's description of the finely divided muds from the stagnant area of the South Bight and also from the flats one mile to the west of the west end of the South Bight is particularly significant. He mentions Drew's researches, in which the latter found that the mud off Andros Island contained 160,000,000 bacteria (*Pseudomonas calcis*) per cu. cm. but was characterized by almost complete absence of other organisms. Drew states

that the carbonate mud was probably formed by the metabolism of the bacteria. I have examined this material in the lagoons at Tortugas and find that it is not quite so pure in every case but is apt to contain large quantities of minute animal matter such as the tests of Foraminifera, etc. It is very plastic, sun-cracks readily, and when exposed to the air for a short time becomes exceedingly hard, so hard in fact that it can not be easily dissolved again in water. Its chemical and physical characteristics are quite similar to those of the limestone in the unfossiliferous zones of the Stones River group, and I believe that a careful study of the shoal-water deposits off the southeast coast of Florida, especially in the region of the Bahamas, will yield valuable data for comparison with those of the Lower Paleozoics.

"On the west side (of Andros Island)" according to Vaughan "there is an enormous flat, which is over 60 sea miles wide along an east and west line, and on it the maximum recorded depth is three and one-half fathoms.

"It is probable that, especially during the summer months, the temperature of the shoal waters is higher than on the surface of the ocean where the depths are greater. Such an increase in temperature would cause the water to lose $CO_2$ and produce precipitation of $CaCO_3$. Surface agitation of the water would accelerate the loss of $CO_2$ and thereby increase the rate of precipitation of $CaCO_3$."

"From the foregoing discussion it is obvious that there are at least three cooperating factors tending to produce precipitation of $CaCO_3$, viz: (1) Ammonifying bacteria, (2) concentration of salts in solution through evaporation, (3) expulsion of $CO_2$ by increase in temperatures. As these factors have not been evaluated, a satisfactory solution of the complicated problem awaits further research" (op. cit., pp. 273-274).

Although the Valentine limestone has not the characteristic "Birdseye" appearance, the thin, thread-like particles of pure calcite which are clearly seen in the hand specimen may be evidence of the former existence of a marine plant, or Nullipore, which flourished at the time of the deposition of the fine, limy muds. The lack of any definite organic structures, however, either in the hand specimen or under the microscope, makes this hypothesis even more indefinite than that regarding the Lowville of New York. It is therefore suggested that the original oozes out of which the Valentine limestone resulted may have been formed, partly at least, by the metabolism of some low form of organism similar to

*Pseudomonas calcis.* The validity of Vaughan's speculations regarding the precipitation of calcium carbonate by inorganic agencies is not yet fully established, and these agencies may also ultimately prove to be important factors in the formation of both calcium and magnesium carbonates.

*Center Hall Formation.*—In order to procure fresh quarry-rock uncontaminated by the talus which accumulates from the argillaceous limestones of the hanging-wall, the American Lime and Cement Co. has sunk a shaft in the purest, upper beds of the Valentine, and is now removing considerable rock by the stoping method. The width of the stope is at present limited by the shaft in the basal beds and by a much less pure zone which it does not pay to quarry. The line of contact between the pure and impure zones above is shown to be gradational, and the upper beds are fairly fossiliferous, the most important fossils being Columnaria nov. sp., *Maclurites logani,* and one or two species of simple corals. Columnaria has been observed on the hanging-wall of the northernmost quarry at Bellefonte but it does not appear to be as abundant at this horizon. To this narrow zone, which occurs above the Valentine and below the highly fossiliferous and lithologically dissimilar Rodman, I have given the name Center Hall, after the village of that name in Penns Valley. The Center Hall formation is only a few feet thick along the Tyrone-Salona line, but it appears to thicken eastward, possibly replacing the upper beds of the Valentine. It is impossible to state definitely at the present time whether or not the Center Hall can be distinguished from the upper Carlim in the eastern sections. There is good evidence, however, that it can not be distinguished at Thorpe's Quarry.

The taxonomic problem of the Stones River formations is a serious one, which will have to be solved, not only for this area, but for numerous sections throughout the Appalachian geosyncline. If one were describing a single section along the Tyrone-Salona line he would be correct in giving formational names to the pure "quarry-rock" and the thin but exceedingly distinctive zone directly underlying the Salona (basal Trenton). Neither of these formations, it is true, is of mapable thickness, but the Valentine is of great commercial importance and therefore should be shown at least on the economic sheet of a geologic folio. The term Rodman has already been

adopted by the United States Geological Survey without a clear or sufficient definition, the description of the formation not being that of the type locality. The propriety of the use of the term Center Hall, strictly from the point of view of the map-maker, is perhaps open to argument. It must be remembered, however, that the ultimate goal of the stratigrapher is not a more or less neatly drawn columnar section but a comprehensive view of the paleogeography of the area in which he is at work, and failure to recognize certain zones in the Bellefonte section would lead to an incorrect picture of the upper Stones River sea.

*Summary of the Stones River Reef.*—The stratigraphical relationship of the Carlim and Valentine formations strongly supports the hypothesis that the former was a "bedded reef" or shallow-water platform upon which flourished, from time to time, dense mats of colonial organisms, while the latter represents the deposits of a broad lagoon, or shallow-water shelf, protected from the action of the open sea. The columnar sections of fig. 2 indicate that the Valentine thins out in a southeasterly direction and that its place is taken by an increased thickness of the Carlim. Figure 3 is a diagrammatic cross-section in a southeasterly direction from Bellefonte through Pleasant Gap and Center Hill to Reedsville. Although the Lemont, Center Hill, and Coburn sections lie respectively to the southeast and northwest of this line, they have been projected upon it for the sake of producing all the evidence upon one diagram.

The basal beds of the Carlim were laid down upon the Loysburg platform in very shallow water, as is indicated by the abundance of mud-cracks, ripple-marks, and edgewise glomerates previously mentioned. During the early stages of the accumulation of the formation, conditions were suitable for the growth of attached colonial as well as other benthonic types which at times formed mats or beds of appreciable thickness and considerable area. *Tetradium syringoporoides, T. fibratum, T. cellulosum,* Girvanella, and numerous species of Bryozoa were important reef-building types.

In the closing stages of the Carlim, Columnaria became relatively more abundant toward the continental side. Toward the west, or open sea, conditions were apparently not suitable for the growth of the reef, and the pure

oozes of calcium carbonate which now form the Valentine were laid down. The absence of fossils in this deposit may be attributed to the nature of the bottom, which at any stage of its growth was unsuitable for fixed or vagrant benthos.[2] The lagoon or off-reef phase appears to thicken slightly to the southeast, the white line on the sketch-map showing the approximate easterly limit of the purest limestone. It has already been pointed out that the extreme southerly sections (Nos. 8, 9, 10) do not contain the Valentine.

The evidence favors the belief that these sections lie to the east of the original area of the purest limestone, as shown by the dotted extension of the white line on the sketch-map.

Toward the close of the Valentine phase of deposition, the calcareous sediments became less pure. A few corals, including Columnaria, and the gastropod *Maclurites logani* reappear. This thin zone, which can be distinguished from the highly fossiliferous beds of the Rodman, is only distinctly observed along the Tyrone-Salona line. It signifies the brief return of Carlim conditions and necessitates a distinct formational name only in the sections where the Valentine is present.

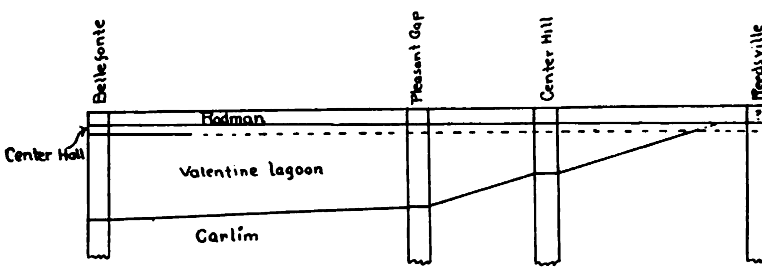
*Rodman Formation.*—The highly fossiliferous limestone of this persistent northeast and southwest zone is considerably less pure than the subjacent formations. It contains many Bryozoa and other types of attached benthos, as is evidenced by the plates of crinoids and also the abundant remains of pelmatozoan stems. The formation is best observed in the west but its lowest beds have been observed as far east as Reedsville. Its fauna and lithology are taken to represent the closing phase of Stones River time. The descriptions of the new species in the prolific and peculiar fauna listed below have already been written and will be published later. The species are: *Streptelasma profundum, S. corniculum, Echinosphærites aurantium, E. aurantium suecica, E. grandis, Hemiphragma ottawaense, Dalmanella rogata, Orthis tricenaria, O. disparilis, Pianodema subæquata,* Leptæna n. sp., *L. charlottæ,* Plectambonites n. sp., Oxoplecia n. sp., *Tetranota obsoleta, Omospira laticincta, Bumastus porrectus, B. transversalis, B.* n. sp., *Illænus*

[2] My recent examination of the lagoons in the Tortugas group bears out this theory.

*angusticollis, I. americanus, Thaleops ovatus, Encrinurus tuberculosus, Calymene senaria.*

*Salona Formation.*—The black argillaceous limestones which follow the Rodman are decidedly different from it lithologically as well as from all of the lower Stones River formations. They appear to attain their maximum thickness at Salona but there is evidence that they also thicken slightly to the east. Although this formation contains a few characteristic fossils such as *Conularia trentonensis, Endoceras proteiforme elongatum,* etc., it is principally characterized by *Brongiartiella trentonensis,* another species of the same genus and several new species of Isotelus. The lowest beds of the Salona contain *Cryptolithus tessellatus,* and its upper beds bear large symmetrical ripple-marks with an amplitude of

FIG. 3.




from one and one-half to two feet. It is closed in all sections by several feet of finely cross-bedded limestone, exceedingly poor in fossils. The Salona undoubtedly belongs to the Trenton group, but since it is decidedly different from the superjacent limestone both faunally and lithologically, and is in fact a phase peculiar to the central Pennsylvanian province alone, the writer has decided to give it a distinct formational name. Salona is a village in the Mill Hall gap and opposite the best exposure of the Trenton in the whole province.

*Coburn Formation.*—The upper Trenton limestone is both faunally and lithologically different from the lower Trenton or Salona. It has thus been recognized as a distinct formation and named after the town of Coburn whose location has already been described. This formation begins in all sections, where exposed, with a well-defined zone of *Parastrophia hemiplicata.* The lower and

middle beds are made up of alternations of crystalline, highly fossiliferous limestone and black shaly limestone. There is usually no sharp distinction between the Coburn limestone and the superjacent Reedsville shale, the beds toward the top of the former becoming increasingly shaly and finally merging into the latter formation. The upper beds of the Coburn, which are particularly characterized by Plectambonites and *Cryptolithus tessellatus,* become increasingly shaly toward the southeast. At Coburn the typical crystalline and highly fossiliferous beds are thinner than at Bellefonte and the upper beds of this formation are made up of very shaly limestone which is characterized by an abundance of *Cryptolithus tessellatus.* The crystalline beds of the Coburn therefore appear to thicken to the west but on the contrary become increasingly shaly as they approach the old upland of Appalachia to the east.

## Correlation with the Middle Ordovician Formations of Eastern North America.

It was pointed out in the first part of this paper that the central Pennsylvanian province occupied, geographically, a somewhat intermediate position between the New York, Mohawkian, or Middle Ordovician terranes on the northeast and those of similar age at Chambersburg, Pennsylvania. The presence in the Carlim of Bathyurus (cf. *B. extans*), Columnaria (cf. *C. halli*), *Maclurites logani,* and other characteristic fossils previously listed, shows this formation to lie above the Beekmantown and below the Trenton. Since the term Black River has now become very indefinite when applied outside of New York State, and since the formations subjacent to the Trenton throughout the central and southern Appalachians are found to vary both faunally and lithologically, I have followed Ulrich in the use of the term Stones River for the pre-Trenton group which lies above the Beekmantown. Although the Salona contains one genus, Brongiartiella, which has not been found anywhere else in the Trenton of North America, the rest of its fauna is upper Middle Ordovician in aspect. The Coburn, on the other hand, contains a long list of typical Trenton fossils.

These two formations have, therefore, been placed under the group name of Trenton.

There is no doubt that the above rough correlation is warranted, but the manner in which the separate formations of central Pennsylvania are to be correlated with the neighboring ones is still open to question. The principal argument concerns the location of the dividing line between the Stones River and the Trenton groups: Shall the Rodman be placed at the top of the Stones River or at the base of the Trenton?

*Stones River.*—The formations above the Loysburg and below the Rodman, i. e., Carlim, Valentine and Center Hall, have been shown to be related in age and mode of origin. The Valentine thins to the east and its beds are successively replaced by the upper beds of the Carlim, the younger of which appears to be synchronous with the Center Hall at Bellefonte. Collie has stated that the Stones River group includes the fossiliferous, fairly pure limestone which follows the Beekmantown, and the superjacent quarry-rock which he likens to the Birdseye zone of New York State. He makes no mention of the Center Hall, however, and what is more important, he also makes no mention of the thin but highly characteristic faunal zone above the pure quarry-rock. Recent and more intensive study of the Appalachian province shows that there is considerable variation in the limestone of Stones River age. If the Carlim is a bedded reef and the Valentine a lagoon or offshore phase, we may account for the slight lithological and faunal variations to the north, south and west as due to such local conditions as distance from shore, presence or absence of marine currents, character of the underlying formations, and possible disturbing influence of large rivers bearing argillaceous or siliceous impurities. To ascribe a different age to each phase is a doubtful proceeding in view of even the little that we know regarding the varied distribution of bottom types in the south Atlantic coral latitudes.

The characteristic fossils of the Carlim are shown in the following table:

| Carlim | Murfreesboro | Pierce | Ridley | Lebanon | Carters Creek |
|---|---|---|---|---|---|
| Cancellospongia n. sp. . . . . . . . . . . (U)* | . . . | . . . . | . . . . | . . . . | X |
| Streptelasma profundum . . . . . . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Columnaria n. sp. . . . . . . . . . . . . . . . (U) | . . . . | . . . . | . . . . | . . . . | X |
| Tetradium cellulosum . . . . . . . . . (L–U) | . . . . | . . . . | . . . . | X? | . . . . |
| Tetradium syringoporoides . . . . (L–U) | . . . . | . . . . | . . . . | X | . . . . |
| Cryptophragmus antiquatus . . . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Rafinesquina minnesotensis . . . . . . . (L) | . . . . | X | . . . . | . . . . | . . . . |
| Protorhyncha ridleyana . . . . . . . . . . (L) | . . . . | X | . . . . | . . . . | . . . . |
| Zygospira recurvirostris . . . . . . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Pterotheca sp. . . . . . . . . . . . . . . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Liospira vitruvia . . . . . . . . . . . . . . . . (L) | . . . . | X | . . . . | . . . . | . . . . |
| Liospira progne . . . . . . . . . . . . . . . . (L) | . . . . | X | . . . . | . . . . | . . . . |
| Thaleops sp. . . . . . . . . . . . . . . . . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Pterygometopus callicephalus . . . . (U) | . . . . | . . . . | . . . . | X | . . . . |
| Leperditia fabulites . . . . . . . . . . . (L–U) | . . . . | X | . . . . | . . . . | . . . . |

* L stands for lower and U stands for upper Carlim.

On strictly faunal data the lower Carlim should be correlated with the Pierce and the upper Carlim with the Lebanon and Carters Creek formations in Tennessee. Columnaria n. sp. and one or two peculiar sponges recently discovered are particularly important horizon markers.

It can now be definitely stated that the typical Leray-Black River does not occur in the central Pennsylvanian province.

The thin zone of slightly less pure limestone which occurs above the Valentine and thickens appreciably to the east is neither faunally nor lithologically particularly different from the Carlim except that it does not contain Tetradium. Were it not for its separation from the Carlim, at Bellefonte, by the intermediate zone of the Valentine, there would be difficulty in distinguishing it from the lower formations.

The recent discovery of the peculiar faunal zone which occurs between the Center Hall and the Salona, and which Butts has named Rodman, introduces an entirely new element into the discussion of the correlation of the

central Pennsylvanian and neighboring provinces. The fauna of the Rodman does not occur in central New

| | Rodman of Penn. | Chambersburg | | Elsewhere |
|---|---|---|---|---|
| | | Marion Penn. | Strasburg Va. | |
| Nidulites favus | ...... | M–U | ...... | ? |
| Zittelella varians | X | ...... | L | Stones River |
| Receptaculites occidentalis | X | L | ...... | Stones River and Trenton |
| Echinosphærites aurantium | X | L–U | L–U | Middle Ordovician |
| Echinosphærites aurantium suecica | X | L–U | L–U | ? |
| Echinosphærites grandis | X | L | ...... | ? |
| Orthis disparilis | X | L | ...... | ? |
| Orthis tricenaria | X | L | ...... | Stones River and Trenton |
| Plectorthis trentonensis | X | ...... | L | Trenton |
| Glyptorthis n. sp. | X | L | ...... | Stones River and Trenton |
| Dalmanella n. sp. | X | L | | ? |
| Dinorthis pectinella | X | L | ...... | Stones River and Trenton |
| Plectambonites n. sp. | X | L | ...... | ? |
| Leptæna n. sp. | X | L | ...... | ? |
| Leptæna charlottæ | X | L | ...... | Stones River |
| Leptæna n. sp | X | ? | ...... | ? |
| Rafinesquina alternata | X | L | ...... | Stones River and Trenton |
| Christiania trentonensis | ...... | U | ...... | ? |
| Oxoplecia n. sp. | X | L–U | ...... | ? |
| Parastrophia hemiplicata | ...... | L | ...... | Trenton |
| Protozyga exigua | X | L | ...... | Stones River and Trenton |
| Cryptolithus tessellatus | ...... | U | ...... | Trenton |
| Ampyx sp. | ...... | L–U | ...... | ? |
| Illænus consimilis | ? | L? | ...... | Stones River |
| Illænus americanus | X | L | L | Trenton |
| Illænus angusticollis | X | L | ...... | Stones River |
| Pterygometopus callicephalus | X | L | ...... | Trenton |
| Ceraurus pleurexanthemus | X | L | ...... | Stones River and Trenton |

* L stands for lower Echinosphærites zone, M for middle or Nidulites zone, and U, for upper Echinosphærites zone of the Chambersburg.

York, it does occur, however, in the Chambersburg area (No. 16), the nearest outcrop to the southwest.

In the following table the fauna of the Rodman is com-

pared with those of the Chambersburg at Marion, Pennsylvania and at Strasburg, Virginia.

It will be noticed that except for the absence of Ampyx in the Rodman, this formation is more readily correlated with the lower than the upper Chambersburg. As Ampyx is found in both the lower and upper Chambersburg and is entirely absent in the Rodman, it is really of no correlation value. On the other hand, since Christiania and Cryptolithus occur only in the upper Chambersburg, and the majority of the Rodman types are also found only in the lower Chambersburg, I believe that these two zones are of the same age and that beds representing the Nidulites zone and the upper Echinosphærites zone are absent in central Pennsylvania.

Ulrich has placed the strata at Chambersburg, which contain the two Echinosphærites zones and the intervening Nidulites zone, in the Black River (Stones River), while Raymond (op. cit., p. 252) assigns the same zones to the Trenton. My own study of the problem shows that of certain species in the Rodman, previously listed, five are Trenton, eight are Stones River and Trenton and four are confined to the Stones River alone. The large number of Illænidæ present give the Rodman a somewhat "Black River" appearance. The absence of Cryptolithus and the fact that this trilobite does occur at the base of the Salona would seem to preclude this horizon from the Trenton. It is true that there are always from 40 to 100 feet of Trenton below the lowest Cryptolithus beds in New York State and elsewhere, but Raymond himself places the Athens (Normanskill) below the Trenton in spite of the fact that this formation contains Cryptolithus. Whether or not the whole of the Chambersburg belongs in the Stones River group may be open to question. It is fairly obvious, however, that the lower Chambersburg and the Rodman are of the same age. When the Valentine is absent, as at Roaring Spring, the difference in lithology between the Rodman and the Salona is certainly much greater than that between the Rodman and the Carlim, and it is for this reason, as well as on account of the fact that the fauna of the Rodman is neither more Stones River than Trenton in general appearance, that I prefer to place the Rodman at the top of the Stones River group.

*Trenton Group.*—Collie has placed all of the limestone above his "Black River" in the Trenton, stating that the fauna is decidedly Trenton in aspect. The Salona

or basal Trenton has been shown to be distinguishable, both lithologically and faunally, from the upper Carlim and Coburn. The fact that the first Cryptolithus zone occurs at the base of the Salona and not in the Rodman probably indicates the base of the Trenton group. Raymond (op. cit., p. 295) has correlated these beds with the 20 feet of Hermitage in Kentucky, principally because of the occurrence of Cryptolithus at the base and of *Orthis tricenaria* and *Dinorthis pectinella* throughout. The succeeding formations of the Trenton group in Kentucky, i. e., Bigsby, Catheys, etc., are not comparable either lithologically or faunally to the Coburn.

The recent discovery of the *Parastrophia hemiplicata* zone just above the cross-bedded and ripple-marked Salona is a fair indication of the beginning of the Middle Trenton of New York State.

There are three Parastrophia zones in the New York Trenton, at the base, middle, and near the top. The oldest or lowest species of the genus is somewhat similar to the primitive type, *P. pristina,* found below the Rodman. The two species which are found in the middle and upper zones are not distinguishable but both are similar to the species found at the base of the Coburn. Platystrophia, common in the middle and upper, and *Rafinesquina deltoidea* in the upper Trenton of New York, are absent in the Coburn. Collie reports a Platystrophia from the section at Bellefonte but I have been unable to find it in any of the sections.

The following composite section of the New York Trenton is copied from Raymond. (Op. cit., p. 253.)

Utica shale with Cryptolithus at top.

| | | |
|---|---|---|
| *g.* | Trenton.—Light-grey, coarse-grained coquina in thick beds. *Rafinesquina deltoidea, Hormotoma trentonensis* and other fossils ................ | 20 feet |
| *f.* | Thin-bedded, blue limestone with shaly partings. *Rafinesquina deltoidea* the common characteristic fossil ........................................ | 92 " |
| *e.* | Thin-bedded, blue limestone with shaly partings. *Prasopora simulatrix* and other common Trenton fossils abundant ........................... | 100 " |
| *d.* | Thin and thick-bedded limestone, dark in color and fine grained. *Diplograptus amplexicaulis* a common fossil ................................ | 35 " |
| *c.* | Thin-bedded, dark limestone with *Triplecia extans* | |

| | | |
|---|---|---|
| | and other fossils. (*Parastrophia hemiplicata* occurs in this zone at Rathbone Brook, New Port, New York State. Fide T. C. White) .......... | 20 feet |
| *b.* | Thin-bedded, dark limestone with some interbedded, coarse-grained layers. *Cryptolithus tessellatus* the characteristic fossil. *Trematis terminalis, Platystrophia trentonensis, Calymene senaria* and many other fossils present ........ | 41 " |
| *a.* | Thin-bedded, grey limestone with an abundance of *Dalmanella rogata,* and some other fossils ...... | 32 " |
| | | 346 feet |

The 400 feet of the Coburn compare very favorably with the 155 feet (beds c to e, inclusive) of Raymond's section. Since beds f and g are characterized by *R. deltoidea,* which fossil is absent in the Coburn, it appears as if the shale deposition began earlier in the Pennsylvanian province. The lower 72 feet of the New York section (lower Trenton) differ from the Salona in lithology and also in the absence of *Brongiartiella trentonensis.* The lower Trenton of Kentucky as described by Ulrich (op. cit., p. 1) may be summarized as follows:

Hermitage formation.—Thinly-bedded to medium-bedded, fine-grained to granular limestone and shale ......50 feet.

Thin, evenly bedded, argillaceous and siliceous, blue layers of limestone, separated by seams of blue or greyish shale .......................20 feet.

None of the fossils listed by Ulrich from this formation are particularly characteristic of the Salona. In Foerste's list (13) Cryptolithus is shown to occur in the Hermitage.

For the present it seems best to refer the Salona to the basal Trenton. Thus the first 234 feet of Raymond's composite section of the New York Trenton is comparable to the 640 feet of the Trenton group in Pennsylvania. The Salona is placed at the base of the Trenton group and the Rodman at the top of the Stones River, but with the admission that this conclusion may be only temporary and is largely dependent upon conditions as found only in the central Pennsylvanian province.

## Bibliography.

(1). A Geological Hand Atlas of the Sixty-seven Counties of Pennsylvania, 1874-1884, by J. P. Lesley. Second Geological Survey of Pennsylvania, Report of Progress X, 1885.

(2). On the Relative Position of the Transition and Secondary Coal Formations in Pennsylvania, and Description of some Transition Coal or Bituminous Anthracite, and Iron Ore Beds near Broad Top Mountain, in Bedford County, and of a Coal Vein in Perry County, Pa., with sections, by Richard C. Taylor. Trans. Geol. Soc. Penn., **1**, pt. 2, p. 192, and pl. 7, no. 3, 1835. Also, Notice as to the Evidences of the Existence of an Ancient Lake, which appears to have formerly filled the Limestone Valley of Kishacoquillas, in Mifflin County, Pennsylvania. Ibid., p. 200, pl. 9, fig. 2.

(3). The Geology of Pennsylvania, by Henry Darwin Rogers, State Geologist. In 2 vols. and Atlas. Philadelphia, J. B. Lippincott & Co., 1858.

(4). Second Geological Survey of Pennsylvania, 1874-5-6. Historical Sketch of Geological Explorations in Pennsylvania and other States, etc., by J. P. Lesley, pp. 42-43, 1876.

(5). Ordovician Section near Bellefonte, Pennsylvania, by George Lucius Collie. Bull. Geol. Soc. America, **14**, 410 et seq., 1903.

(6). Types of Sedimentary Overlap, by Amadeus W. Grabau. Ibid., **17**, 619-620, 1909.

(7). Revision of the Paleozoic Systems, by E. O. Ulrich. Ibid., **22**, 660, 1910.

(8). Expedition to the Baltic Provinces of Russia and Scandinavia, by Percy E. Raymond. Bull. Mus. Comp. Zool., **6**, 239, 1916.

(9). Geologic Section of Blair and Huntingdon Counties, Central Pennsylvania, by Charles Butts. This Journal (4), **46**, 525-526, 1918.

(10). A Preliminary Paper on the Classification of Intraformational Conglomerates and Breccias, by Richard M. Field. Ottawa Naturalist, **30**, 29-66, figs. 1-3, 1916.

(11). Paleozoic Intraformational Conglomerates, by Charles D. Walcott, Bull. Geol. Soc. America, **5**, 191, 1894.

(12). Some Shoal-Water Bottom Samples from Murray Island, Australia, and Comparisons of them with Samples from Florida and the Bahamas, by T. Wayland Vaughan. Papers from the Department of Marine Biology, Carnegie Institution of Washington, D. C., **9**, 239-288, 1918.

(13). Kentucky Geol. Survey, Foerste (4), **1**, 372, 1913.

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Cambridge, Mass.

**Art. XXVIII.**—*Note on an unusual Method of Rounding of Pebbles in sub-arid Western Australia;* by J. T. Jutson.

## Introduction.

The observations recorded in this paper are based on pebbles found at Goongarrie and Comet Vale[1] at the base of cliffs on the western shores of Lake Goongarrie—a "dry" lake or playa—and on adjacent hills. The places referred to are in that part of sub-arid Western Australia where the average rainfall does not exceed 10 inches per annum.

## Description of the Pebbles.

For the purposes of description, the pebbles may be divided into two classes:— (*a*) greenstones,[2] chiefly fine-grained, and (*b*) soft sediments (comprising grits and shales) and soft decomposed foliated quartz porphyries.

The greenstone pebbles occur at Goongarrie on the slopes and tops and at the foot of the greenstone hills, which form the western border of Lake Goongarrie,[3] and which rise about 100 feet from the lake country. They vary in diameter from an inch to three or four inches, and may be roughly circular, elliptical or lens-shaped in outline. Some pebbles have the whole surface well rounded, but others have their surfaces angular and uneven. At the foot of the hills and occasionally on small ledges on the hillsides the pebbles are often greenish-gray (the natural color of the rock), and almost devoid of any foreign coat of film such as iron oxide; a fact which makes such pebbles more conspicuous than those elsewhere on the hills, as the latter pebbles are usually more or less coated with a film of iron oxide, which harmonizes with the prevailing color of the surfaces of the rocks around. The pebbles are scattered but fairly numerous; yet no distinct accumulation anywhere occurs, except possibly on a small scale at the foot of the hills.

Most of the fine-grained greenstones in the interior of

[1] The township of Goongarrie is 55 miles and that of Comet Vale 63 miles north of Kalgoorlie.

[2] "Greenstones" is a common field term in Western Australia for a variety of basic igneous rocks, such as dolerites, gabbros, amphibolites, and other similar rocks.

[3] The normal main lake does not reach to the foot of the hills, where most of these pebbles have been found, but what is practically a westward extension of the main lake does so reach.

Western Australia are rather minutely jointed and under the influence of the weather they break up into thousands of angular fragments, averaging perhaps in size, in all dimensions, about three inches. The faces of the joint planes near the surface of the ground are generally coverd with a film of iron oxide, giving a brownish-red appearance to the rocks. The tops and slopes of the hills are littered with these fragments. It is this coating of iron oxide that plays an important part in regard to the pebbles.[4]

The pebbles of the sediments and porphyries, which are usually soft and easily broken, have been observed at the foot of cliffs on the western shores of the lake and at the eastern end of an island in the lake. The pebbles are associated in places with smooth rounded "knife-edges" of the rocks *in situ*. The pebbles are generally, but not always, thin and flat; are roughly circular, elliptical or lens-shaped in outline; and attain three of four inches in length. The flat surfaces are in places irregular and rough, and in some pebbles, both flat and otherwise, the rounded outlines do not extend over the whole surface.

The shapes assumed by the pebbles are controlled by the shapes of the original rock fragments. This point has been well brought out for practically all pebbles by H. E. Gregory.[5]

## Causes of the Rounding.

Two hypotheses, which immediately suggest themselves to account for the rounding, may be considered. They are:— (*a*) abrasion through the agency of the waters of a lake or an arm of an ancient sea; and (*b*) abrasion due to stream action. Both are rejected and for the following reasons:—

(1)—The pebbles are always found close to rocks *in situ*, with which they are identical in composition and structure, it being quite clear that the pebbles are derived from these rocks. In one place, successive thin bands of rock of different texture and composition have been observed to have corresponding pebbles immedi-

[4] Oxide of iron films on rocks affect rock weathering in other ways, which however, the writer proposes to discuss in other papers.

[5] "Note on the Shape of Pebbles," this Journal, vol. 39, pp. 300-304, 1915.

ately adjacent. Moreover, rocks, rounded at the surface, may be seen breaking away from the parent mass.

(2)—The greenstone pebbles are scattered at all heights from the bottoms to the tops of the hills. This fact, therefore, precludes the action of lake waters and also of stream action, unless, in the latter case, the pebbles were laid down on the tops of the hills (when the general land surface stood approximately at the height of such hills) and have been subsequently transported by gravitation down their sides. The close proximity of the parent rock to the pebbles, however, is against this possibility.

(3)—Strong water abrasion would reduce most of the soft sediments and porphyries to powder rather than form rounded pebbles.

A third hypothesis is spheroidal weathering, which, although operating among the greenstones by flaking, as described below, does not appear to meet all the facts. No actual peeling of concentric coats, in either of the classes of pebbles described, has been seen; and the stratified sediments and decomposed foliated porphyries are not favorable rocks for this mode of weathering.

A fourth hypothesis that they are derived from old conglomerates is equally untenable in view of their clear relationship to the rocks *in situ,* as already shown.

In the greenstones, the iron crust or film on the joint faces is important. Until broken by ordinary weathering agencies no rounding, as a rule, takes place, but once the crust is penetrated it tends to be slowly removed over the whole surface, and the grey rock within begins to assume a rounded form. Examples are obtainable of various stages of this destruction of the crust. An iron crust does not cover the sediments and porphyries observed, hence the process of pebble formation is not delayed for a time as in the greenstones.

Flaking in small fragments, owing to temperature variations, may and probably does take place in the rocks of both classes of pebbles; but in the case of the greenstones practically only when the crust has been broken. This flaking may be regarded as a phase of spheroidal weathering, and doubtless is partly responsible for the greenstone pebbles. The chief agent, however, of the rounding of the other class of rocks, and a major or minor agent in the formation of the greenstone

pebbles seems to be the direct action of the rain in beating upon the surfaces of the rocks (in the case of the greenstone when the iron crust has been broken) and wearing them away without any rock particles to act as abrasion tools. Under this action the corners are most likely to be first removed and hence the rounded appearance. There may also be some latent structure in the rock which, despite the angular jointing, assists rounded weathering; but this would hardly seem to apply to the thin-bedded sediments and decomposed foliated porphyries. The unrounded irregular under surfaces of many of the sediment and porphyry pebbles may be accounted for by the fact that the rain cannot beat directly on such surfaces. Where, however, a pebble has been rounded on its whole surface, this appears to be due to all portions having been directly exposed at different times to the rain, owing to the rock fragment which became the pebble having changed its position by reason of the slow gravitational movement, which all loose fragments are subject to, and which is especially well illustrated in sub-arid Western Australia.

The greenstone pebbles are also more abundant and freer from iron oxide films at places such as the base of a hill or on a tiny bench on the hillside, where the flow of the surface rain water has been more concentrated than usual, or where it may have lodged for a little while. The flow, however, has been so insignificant that it cannot have any direct abrasive power akin to normal stream action, but it seems to act in keeping the surfaces of the rock fragments largely free from the deposition of iron and hence assisting their rounding by the rain. At the foot of the hills, percolating meteoric water may ooze out and act in the same way. Certainly in other places than those mentioned the pebbles have more iron oxide films, and their disintegration must therefore be retarded. It is the occurrence of the grey pebbles at the foot of lake cliffs that suggests, until a closer investigation has been made, that they are normally waterworn pebbles due to their abrasion by stream, lake or old sea waters.

Wind action has probably had some slight effect on the pebbles, but that need not be discussed here.

Fragments of decomposed rocks from the oxidized zone thrown out from mining shafts sunk on the West-

ern Australian goldfields, have in places become quite rounded on those portions exposed to the weather since their removal from below the surface; and the beating of rain appears to be the cause of this.

At a mine inspected by the writer, a number of greenstone pebbles, well-rounded and apparently truly water-worn by abrasion, were shown as having been ordinary angular fragments brought to the surface and rounded by water splashing them from the pump. This explanation was not accepted as genuine at the time, although the good faith of the informant was not questioned; but the pebbles were regarded as having by some mischance found their way to their then position. In view, however, of the observations on which this paper is based the writer believes that the statement made as to their origin is probably true.

The greenstones of the Western Australian goldfields are usually much altered rocks chemically and mineralogically, and this alteration may assist the mode of weathering here described, but further investigation is necessary to come to a conclusion on this point.

### Comparison with rock fragments in adjacent Canyons.

The country of which the greenstone hills referred to above form a part, is dissected into young steep V-shaped canyons up to 100 feet in depth, which are entirely due to normal stream erosion. Consequently, it is interesting to compare the greenstone rock fragments there found with those described in this paper. Careful observation shows that the rock debris of the stream channels is, on the whole, angular or sub-angular, hardly any fragments having more than their corners rubbed off and blunted. The rounded forms described in this paper are quite absent, so that it is clear that stream abrasion under present conditions cannot produce these forms. As, however, the stream channels are dry nearly all the year it is difficult to understand—if past erosive action be rejected—why such rounded pebbles are not produced in the stream beds by the same agents that are producing them on and at the foot of the hills as described in this paper, especially as the stream rock fragments are of similar rocks and largely free from iron films. The only suggestions as to the reason of this that the writer can make are that the rock frag-

ments of the water channels are being moved fairly fast down stream by the intermittent stream action, and that this movement prevents the rain from beating long enough on one particular surface to bring about the rounding;[6] and also that when rain falls the channels must at times receive sufficient water to cover the debris on their floors, and thus prevent further direct falls of rain on to the rock fragments. Be this as it may, the explanation given for the rounded pebbles of the hill-sides, and at their bases on lake shores, appears to be the only feasible one. It at least appears certain that they are being rounded in their present positions, and that they are not due to past normal stream, lake, or marine action.

### The Bearing of the Origin of the Pebbles on Certain Questions.

A true conception of the origin of the rounded pebbles is required in view of the incorrect inferences that may be drawn from their occurrence, if such pebbles are assumed to be due to either stream, lake, or marine action; such inferences must be that large rivers or lakes (probably freshwater) earlier existed in the area; or that the land has been recently subjected to marine erosion. The nature of the pebbles does not support any of these deductions.

H. E. Gregory has shown that, under certain conditions, pebbles may be carried considerable distances by streams and yet remain angular or sub-angular,[7] and that ancient river gravels may not in all cases be distinguishable from residual deposits resulting directly from weathering.[8]

In the area of which this paper treats, these statements are confirmed to the extent that the true stream-borne pebbles are angular and sub-angular, while the rounded pebbles have received their present shapes in practically their present positions, which are close to the parent rocks. The angular character of the stream-borne pebbles may however, be entirely due to the short distance they have travelled.

Perth, Western Australia.

[6] The absence of rounding in these stream fragments would also seem to imply that flaking is not a very potent agent in the formation of the greenstone pebbles described in this paper.
[7] Op. cit. p. 302.
[8] Op. cit. p. 303.

# Art. XXIX.—*Sheet-flows, or Sheet-floods, and their associated phenomena in the Niagara District of sub-arid south-central Western Australia;* by J. T. Jutson.

## Introduction.

Sheet-floods occur in arid and sub-arid countries, the classical exposition from a physiographic standpoint being that by McGee[1] in regard to an area in North America. He attributes considerable erosive power to the sheet-flood, but his conclusions have not been generally accepted by American physiographers and geologists.

Sheet-floods occur in the sub-arid portions of south-central Western Australia, but so far as the writer is aware, no detailed description of them has ever been given, nor has their work in the rôle of erosion been discussed. The present paper is therefore a contribution to the subject.

It may at once be stated that the sheet-floods here dealt with do not, in the writer's opinion, possess the erosive activity attributed by McGee to the sheet-flood in the area specially studied by him; but the writer does not presume to question McGee's conclusions for that area. This paper is only concerned with the manifestation of the sheet-flood in sub-arid south-central Western Australia, as exemplified in the Niagara District.[2] The term "sheet-floods," however, will not be used; "sheet-flows" appear to be more suitable to describe the widespread moving sheets of water as a whole, some of which are quite gentle in their action, and could hardly be classed as floods.

## Summary.

Sheet-flows in sub-arid south-central Western Australia are broad, shallow, but not necessarily continuous, sheets of water, which traverse the gently-sloping sides and the flat bottoms of wide, open, shallow valleys, and the floors of plains. They are divided into three classes,

[1] McGee, W. J.: "Sheet-flood Erosion." Bull. Geol. Soc. Am. vol. 8, pp. 87-112, 1897.

[2] Niagara is a decayed mining township on the great sub-arid plateau of Western Australia. It is 118 miles north of Kalgoorlie and is 1460 feet above sea-level. The average rainfall is slightly under 10 inches per annum.

namely: the rill type, the smooth-bottomed valley type, and the furrowed-floor type. They appear to be rather agents of deposition than of erosion. The term "sheet-flows" is used in preference to "sheet-floods," so as to include all kinds of wide, shallow, moving bodies of water, no matter how gently they may flow.

## Description.

Sheet-flows, as noted above, may be divided into three classes, which vary according to the nature of the ground over which they flow. The divisions are perhaps somewhat arbitrary, but the types exist and the classification is convenient for reference and description.

1. *Rill type.*—This type consists of the broad sheets of water which flow down the smooth surface of the long, undissected gently-sloping sides of shallow, wide, open slowly-corrading valleys. There is no limit as to the width of water that may flow, except the length of a valley side, and the area affected by the fall of rain, which has caused the occurrence. The water is not actually continuous across the line of flow, but the sheet is made up of countless rills of varying width, and not separated by more than a few feet. These rills may be merely films of water not more than one inch in depth or they may reach a depth of perhaps six inches, this variation being due to the very slight inequalities of the ground. The flow is so widespread and shallow that even with a moderate slope, and on soil-covered areas, the water usually has no power of cutting even the smallest trench or furrow; the surface of the ground remains quite smooth and unbroken, although the spaces between the small trees and shrubs are commonly bare of vegetation.

The water will however, if possible, concentrate itself, as is shown where ruts are worn in the surface by cart wheels. It takes possession of these ruts and deepens them, to form a narrow shallow channel, the width of which seldom exceeds the width between the two wheel ruts, and the depth of which is scarcely ever more than 2 feet, so little power of excavation does the water possess on these broad gentle slopes. In fact, in many places the channel tends to become filled by drifting sand, which the flow of water is unable to remove. The mile-upon-mile of very gently-sloping soil-covered ground

which is yet absolutely smooth and unfurrowed,[3] forms one of the most striking features of the country.

The rills of water have no power to directly move forward the angular fragments, of various sizes, of quartz, jasper and ironstone, which are frequently spread over the surface of the ground.

On soil-covered gentle slopes, these rills of water help to form minute soil-terraces from 1 to 6 inches in height. These terraces are primarily due to the occurrence of a surface film of soil, more compacted than the portions beneath, owing to the deposition of material on evaporation of water brought to the surface by capillary attraction.

2. *Smooth-bottomed valley type.*—This type occurs in wide flat-bottomed valleys which generally have a moderate amount of vegetation in the form of small trees, and large and small shrubs. These valleys possess a fairly well-marked drainage line along their floors, by means of one or more channels, which are from 6 to 20 feet wide, are usually not more than 4 or 6 feet deep, and are almost wholly cut through detritus. It is seldom that there is but one channel, although there may be a main one, for the tendency is to form several, which, however, frequently die out, unite and reform. In other words the drainage line is "braided."

These channels occur in wide, smooth, level, soil-covered flats, which consist of detritus (chiefly fine), brought down by the water and spread evenly over the floor of the valley, the long gently sloping sides of which rise gradually from such floor. As the valley is followed downstream the flats become wider and wider, and the valley sides less and less pronounced, until practically a slightly undulating plain results, often without distinct drainage lines.

The channels of the better defined portions of the valley are the main carriers of the water. The latter comes from the hillier country, where of course in the narrow valleys the erosive power of the water is great, also from the numerous rills, which form the first type of sheet-flow; and it naturally collects in and follows the channels. The rains need not be very heavy or lasting before the water overflows into a broad, shallow sheet, which

[3] If the country be of the sandy loam or loamy sand type with abundant "mulga" scrub much of the water will rapidly soak into the ground.

covers or partly covers, according to the volume of the water, the soil-covered flats. Along the latter, floating vegetation in the form of leaves, twigs and small branches of trees and shrubs is carried by the water, and becomes caught at the base of the growing vegetation, remaining there for a time as evidence of the width of the flow of the water. When the rain ceases, and the channels become relieved, the water on the flats tends to gradually drain to the channels, but much is left as pools which gradually disappear by soakage and evaporation.

The main function of the water outside of the channels appears to be neither to corrade nor to transport but to deposit fine detritus; and thus to widen, raise and smooth the general valley floor. This is due to the loss of velocity by the spreading out of the water, aided by the obstructing vegetation. The general scarcity—so far as the writer's observations go—of pebbles on these flats,

FIG. 1.

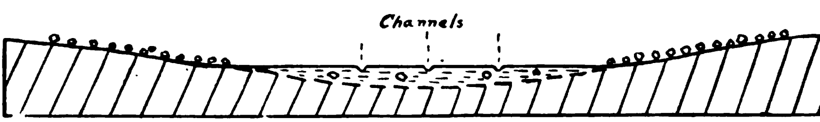


FIG. 1. Cross section illustrating smooth-bottomed valley type of sheet-flow.

Shows bedrock below with surface debris on slopes above; in center, fine detritus with occasional pebbles. It is to be noted that some sandy slopes are almost free from rock debris.

and in natural or artificial cuts through them, also indicates the low transporting power of the water. This scarcity of pebbles is in places in marked contrast to the gently sloping sides of the valley, which may have abundant rock fragments up to three inches in length on their surfaces.

The above statement is generally true for the class of country described, but of course modifications may occur, such as the surface being somewhat furrowed instead of smoothed; and minute soil-terraces may occur where any slope exists.

3. *Furrowed-floor type.*—This type is particularly characteristic of some wide, treeless, or almost treeless, salt bush and samphire flats, which form such a prominent feature in the landscape. These flats may be several miles wide, and in places lie between ridges which tend to rise sharply from the plain, thus forming a broad

flat-bottomed "valley"; or they may be extensive areas without any definitely observed relation to the drainage, except that they are low-lying portions which may communicate with lakes or which may practically form shallow basins with no outlet. Probably most of these flats possess a certain fall for at least part of their areas, and this fall enables the water, after heavy rain, to flow along in broad thin sheets.

The absence of definite channels is a marked feature, but in lieu of these, much of the flat may be scored by very numerous furrows averaging perhaps 9 inches in depth and 18 inches or 2 feet in width. These furrows frequently join one another, and as frequently die out, fresh ones taking their places. The absence of trees and tall shrubs and the presence of the salt bush and other small shrubs, mostly not more than 2 feet high, together

FIG. 2.

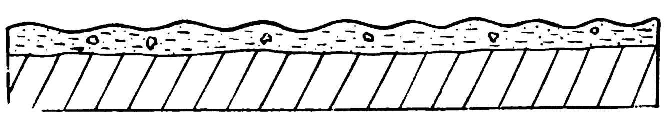

FIG. 2. Cross section illustrating furrowed-floor type of sheet-flow. Bedrock below with fine detritus containing occasional pebbles above.

with the covering of detritus of sands and muds, facilitate the formation of these furrows. The water sweeps and swishes around and among the small shrubs, scouring the detritus out to form furrows, and depositing it around these shrubs until they may be half buried. The furrows must be ever changing as the ever varying small streams gouge out in one place and fill up in another.[4]

The irregular distribution and heaping up of the detritus enable, on the cessation of the rain, numerous small pools to be formed, the water of which soon soaks into the ground or evaporates. The net result of much of the water action seems to be merely the redistribution of the detritus over much of the area, although rock waste must, of course, be continually brought from the higher portions of the country. Much of the fine waste, however, is no doubt removed by the wind.

Perth, Western Australia.

[4] Wind action has probably some effect in both the formation and removal of these hillocks. The latter are comprised in the "Neulinge" of Walther. See "Das Gesetz der Wüstenbildung," 2d Ed., pp. 70-71, 1912.

## Art. XXX.—*Cacoclasite from Wakefield, Quebec;* by N. L. Bowen.

In 1883 crystals of a mineral found in blue calcite near Wakefield, Quebec, were described by Lewis[1] and given the specific name cacoclasite. Later they were further investigated by Genth in particular,[2] who proved that the crystals were made up of a mixture of materials and were, therefore, pseudomorphs and not entitled to rank as a mineral species. Genth's chemical investigation led him to believe that the crystals were a mixture of quartz, calcite, apatite and material of indefinite composition and that they were pseudomorphs after scapolite. Cacoclasite is apparently peculiar to this Canadian locality.

In looking over some material from Wakefield in the University collection, fine specimens of this cacoclasite were noted and in checking their nature under the microscope it was found that the mixture represented does not correspond with that deduced by Genth and is, in fact, considerably simpler. The material was examined in powder form in immersion liquids, a method that is particularly well adapted to the identification of the constituents of a fine-grained mixture. Cacoclasite may have crystals of other minerals coating its surface and these may project into it but, if a crystal free from such foreign material is selected and crushed for microscopic examination, it is found to consist of only three minerals. Calcite ($\omega = 1{\cdot}66$) is fairly abundant and apatite ($n = 1{\cdot}645$) is present in small amount but the main constituent is an isotropic substance of index 1·74. No quartz is to be seen. If some of the powder is warmed with hydrochloric acid, calcite and apatite are removed and the residue is made up entirely of the isotropic substance. This substance shows no sign of cleavage and even after boiling with strong HCl, there is no suggestion of attack. It is evidently the mineral grossularite.

That the cacoclasite consists of grossularite, calcite and apatite is borne out in a most striking manner by Genth's analyses. He gives two analyses of which that numbered I was made on the "best" material. It is given below together with a recalculation of the mineral constituents represented.

[1] Proc. Acad. Phila., 1883.
[2] This Journal, 38, 200, 1889.

Composition of Cacoclasite (Genth).

| | | Mols. | Calcite | Apatite | Rest. | Ratio. |
|---|---|---|---|---|---|---|
| $H_2O$ | 1·04 | | | | | |
| $CO_2$ | 6·73 | ·153 | ·153 | | | |
| $SiO_2$ | 31·52 | ·523 | | | ·523 | 3·02 |
| $P_2O_5$ | 2·19 | ·015 | | ·015 | | |
| $Al_2O_3$ | 17·34 | ·170 | | | ·170 | 1·00 |
| $Fe_2O_3$ | 0·51 | ·003 | | | ·003 | |
| MgO | tr. | | | | | |
| CaO | 40·95 | ·729 | ·153 | ·050[a] | ·526 | 3·04 |
| $Na_2O$ | tr. | | | | | |
| $K_2O$ | tr. | | | | | |

[a] Incl. CaO = $CaF_2$.

The material analyzed by Genth was evidently, grossularite 78·8 per cent, calcite 15·3 per cent and apatite 5·2 per cent. Believing that his tests indicated the presence of free quartz, Genth decided that it was a mixture of quartz, apatite and calcite with an indefinite mixture of other minerals. It is worthy of note that Haines' analysis likewise shows a ratio $SiO_2 : Al_2O_3$ of almost exactly 3.

Genth's "best" material evidently corresponds exactly with the best material powdered for microscopic examination. In the case of Genth's analysis No. II on poorer material, it is necessary to assume that it represents, besides the three above constituents, about 7 per cent kaolinite and 2 per cent tremolite, both of which are to be found on microscopic examination of cacoclasite into which crystals of other minerals project. They are commonly tremolite needles, sometimes changing to talc and prisms of scapolite (?) altered to kaolin. In no case does the microscope reveal the presence of quartz and it can only be assumed that the method adopted by Genth of distinguishing free silica from the silica of a silicate was not to be relied upon.

Genth expresses the opinion that cacoclasite is secondary after scapolite. This conclusion is hardly borne out by the measured values of the angles. While occasionally prismatic, cacoclasite usually has the appearance of a cubo-octahedron. Its departure from isometric symmetry is not obvious and it is necessary to measure the angles before it becomes apparent. The faces are always rough, with an eroded appearance and a peculiar glazed surface. Frequently, they are distinctly concave. By placing a drop of oil on a face and covering with a cover slip, one obtains a plane parallel to the face and capable of giving a good reflection. Using this method and

avoiding concave faces, angular values for cacoclasite were obtained that are believed to be fairly reliable. The values are very close to those for sarcolite with which they are compared below. The relationship of cacoclasite to sarcolite in angles was noted by Lewis.

| Sarcolite. | Cacoclasite. |
|---|---|
| $c\ r = 51° 27'$ | $51° 29'$ |
| $c\ e = 41° 35'$ | $41° 46'$ |
| $a\ r = 56° 26'$ | $55° 43'$ |

The great similarity in angles and the identity in habit make it necessary to regard cacoclasite as a pseudomorph after sarcolite. Sarcolite has the composition $(Ca,Na_2)_3Al_2(SiO_4)_3$ and in its typical occurrence $Ca : Na_2 = 9 : 1$ nearly. The change from sarcolite to grossularite $Ca_3Al_2(SiO_4)_3$ is, therefore, not a great one, indeed it might be termed paramorphism without seriously stretching the truth. A marked decrease of volume is involved, however. Sarcolite of the composition of its typical locality ($G = 2{\cdot}9$ Rammelsberg) would give a volume of grossularite ($G = 3{\cdot}5$) approximately equal to 75 per cent of its own volume. It is worthy of note, therefore, that the "best" cacoclasite of Genth contains approximately 75 volume per cent grossularite. This correspondence suggests that cacoclasite was formed by the alteration of sarcolite to grossularite without change of volume, the resulting voids being occupied by calcite and apatite.

## Summary.

Chemical, microscopic, and crystallographic evidence all point to the fact that cacoclasite is a pseudomorph (essentially a paramorph) of grossularite after sarcolite with calcite and apatite filling the voids produced by the reduction of volume involved in the change.

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Art. XXXI.—*An Interesting Occurrence of Manganese Minerals near San Jose, California;* by Austin F. Rogers.

For some years a huge bowlder of manganese ore situated on the bank of Penitencia Creek below Alum Rock Park which is about five miles east of the city of San Jose, Santa Clara County, California, bore a placard which proclaimed it to be a meteorite. All geologists familiar with it knew that the so-called meteorite was simply manganese ore, for it showed a dull black mineral recognized to be psilomelane, the common manganese mineral of the Franciscan formation of the Coast Ranges of California. In the autumn of 1918 when restricted shipping facilities created an urgent demand for domestic manganese ores, the city of San Jose, owner of the land on which the bowlder was located, at the request of the government decided to dispose of it. Several hundred tons of high-grade manganese ore* was obtained from it and shipped to a California steel plant.

My attention was called to the manganese ore of a "Alum Rock meteorite," as it was known locally, by a resident of San Jose who presented me with a small specimen from its interior. Great was my surprise to find that this specimen was largely pyrochroite, $Mn(OH)_2$, and not psilomelane. As soon as opportunity was afforded, a visit to the locality was made and a suite of specimens obtained. The minerals identified in the bowlder are: Tephroite, hausmannite, pyrochroite, ganophyllite, rhodochrosite, barite and psilomelane. Of these the first four are very rare, except at Långban, Sweden, and ganophyllite is known only from this locality. Hausmannite is not certainly known in the United States but has been reported from San Luis Obispo County, California. Pyrochroite occurs at Franklin Furnace, New Jersey. Tephroite in this country has been found in but two localities, Franklin Furnace and central Texas.

After the minerals are described, an attempt will be made to determine the relations of the minerals to each other and the character of the deposit. The facts brought out in this discussion may have a bearing on certain geological problems pertaining to the Coast Ranges of California.

* The ore shipped varied in manganese content from 43·2 to 63·5 per cent and averaged 52·6 per cent, according to Dr. W. C. Bailey, City Manager of San Jose, to whom I am indebted for this information.

## Description of the Minerals.

*Tephroite.*—Tephroite as a megascopic constituent of the ore is rare but in several specimens it was noted as a massive grayish red mineral which was at first thought to be rhodonite. It lacks, however, the perfect cleavage of rhodonite, a hand lens showing but traces of imperfect cleavage surfaces. It also has a faint resinous luster different from the vitreous luster of rhodonite. The specific gravity of an impure specimen was found by a rough determination to be about 3·75, but carefully selected fragments with only traces of visible impurities gave a specific gravity of 4·010 (determined on 1·5 grams by pyknometer at 25°C.).

The tephroite is very easily soluble in dilute HCl with gelatinization and the solution gives an abundant test for manganese and faint tests for iron, calcium, and magnesium.

The indices of refraction, determined by the immersion method, are greater than 1·740. Thin sections show almost colorless anhedra with interference colors ranging up to bluish-green of the second order, which proves that the double refraction is higher than that of rhodonite ($n\gamma - n\alpha = 0·011$) but lower than that of olivine ($n\gamma - n\alpha = 0·036$). Polysynthetic twinning is a prominent feature in the thin sections, a property not previously reported for tephroite. In some areas the twinning resembles the albite twinning of plagioclase, but more often it resembles an intergrowth of two minerals. The twinning is recognized largely by differences in interference colors rather than by extinction angles.

Although not often visible in the hand specimens, tephroite in isolated anhedra surrounded by alteration products is seen in many thin sections. For this reason it was probably present in abundance in one stage of the history of the deposit, but on account of its ready alteration only remnants of it are left.

*Hausmannite.*—Hausmannite, on the other hand, can be recognized in many of the hand specimens and in some it is by far the most abundant mineral present. It occurs in crystals which vary from euhedral to anhedral, but are usually subhedral. A few small (1 to 2 mm. in size) euhedral crystals were found and prove to have the following forms: (001), (113), (111), (221), with the unit tetragonal bipyramid (111) as the dominant form. The following measurements were made with the reflection goniometer:

*Interfacial angles of hausmannite.*

| | No. of meas. | Meas. | Record. |
|---|---|---|---|
| (001) ∧ (111) | 4 | 58° 32½′ | 58° 32′ |
| (001) ∧ (113) | 1 | 28 25 | 28 34½ |
| (111) ∧ ($\bar{1}$11) | 4 | 74 5 | 74 10 |
| (001) ∧ (221) | 1 | 71 6 | 72 59 |

In thin sections most of the hausmannite is opaque, but on the edges of the sections some of it is translucent and dark red. A few of the deep red crystals are dark between crossed nicols but most of them are doubly-refracting with definite extinction four times in a revolution. Polysynthetic twinning was noted in some sections.

Crushed fragments of the hausmannite examined with the polarizing microscope under ordinary conditions appear opaque, but in direct sunlight between crossed nicols many of them are translucent dark red. (The crossing of the nicols shuts off the brilliant reflection of the sun and so the fragments are visible.) They are doubly-refracting but the color of the mineral masks the interference colors. This method may be of service in determining some of the submetallic minerals which are opaque in ordinary light, provided of course they are doubly refracting.

The hausmannite is readily and completely soluble in HCl with the evolution of chlorine.

*Pyrochroite.*—The pyrochroite occurs in euhedral crystals (up to 5 mm. in size) in cavities and in cleavable plates in masses. The euhedral crystals are thin lenticular without well-defined faces. A few are hexagonal in outline with a low vicinal rhombohedron. In most specimens the pyrochroite is a bronze-red but soon changes to black on exposure. Freshly broken specimens often show the deep red reflections that give the name to the mineral. In a few cases it is colorless or pale green. It has a perfect cleavage in one direction.

The index of refraction of cleavage flakes was found to be $n\gamma = 1{\cdot}733 \pm {\cdot}003$ (sodium light) which is a little higher than the recorded value (1·723). One of the cleavage flakes gave a negative uniaxial interference figure in convergent light.

In thin sections the pyrochroite is colorless to salmon-colored. The areas without cleavage are non-pleochroic and are either dark between crossed nicols or have very

weak double refraction, while the salmon-colored areas showing cleavage are pleochroic from nearly colorless to deep yellowish-red. The double refraction determined by finding the thickness of a section from the highest interference color of associated barite is about 0·04. The direction of the cleavage traces in thin sections is parallel to the slower ray which checks the optically negative character determined above.

The pyrochroite is also soluble in HCl with the evolution of chlorine and gives abundant water in the closed tube.

Along cleavage planes the pyrochroite in thin sections is seen to be altered to an opaque brown oxidation product. This is a hydrous manganese oxide of some sort and may possibly be the amorphous equivalent of manganite which represent a higher state of oxidation of manganese than pyrochroite.

*Rhodochrosite.*—Rhodochrosite occurs both in euhedral crystals along seams and in granular masses. The euhedral crystals are pink in color and have the form of the negative rhombohedron ($02\bar{2}1$), a common form for calcite, but a very rare one for rhodochrosite. It usually occurs alone, but in a few cases narrow faces of the positive unit rhombohedron ($10\bar{1}1$) were observed. The rhombohedron ($02\bar{2}1$) was identified by the fact that the cleavage rhombohedron truncates its polar edges. This was checked by the following measurements made with the simple reflection goniometer devised by the writer:[1] $02\bar{2}1 \wedge \bar{2}02\bar{1} = 100°$ calc. $= 99°\ 54'$); $02\bar{2}1 \wedge 20\bar{2}\bar{1} = 80°$ (calc. $= 80°\ 6'$).

Some of the specimens are made up largely of fine-grained reddish gray rhodochrosite which shows minute cleavage surfaces. A few light reddish gray specimens seem to consist of rhodochrosite and barite. Rhodochrosite must be common in many specimens even when not visible to the unaided eye, for they effervesce in hot HCl and thin sections show the presence of a rhombohedral carbonate.

*Ganophyllite.*—This very rare mineral, heretofore known only at the original locality (Långban, Sweden), was found along seams with cleavable barite as brownish-

[1] Science (n. s.) Vol. 27, p. 929 (1908). This little device constructed out of a Penfield cardboard goniometer often saves the necessity of using the large reflection goniometer when approximate measurements suffice.

yellow distorted tabular crystals. It was identified[2] by the index of refraction $n = 1{\cdot}723 \pm {\cdot}003$ (recorded values $n\gamma = 1{\cdot}730$; $n\beta = 1{\cdot}729$; $\alpha$ is perpendicular to the plates so that $n\alpha$ is not easily obtained). The plates are pale yellow, non-pleochroic and give a biaxial interference figure in convergent light. The optical determination was checked by qualitative tests for aluminum, manganese and water.

*Psilomelane.*—Massive black and somewhat banded psilomelane makes up the list of manganese minerals that can be positively identified. Before it was broken up to be used as manganese ore, the whole bowlder, or so-called meteorite, was supposed to be psilomelane, but it turns out that only the outside crust is psilomelane.

*Barite.*—Barite seems to be practically the only mineral of the deposit which does not contain manganese. It occurs in euhedral crystals along seams and in thin sections, and it also proves to be interspersed through many of the specimens. The euhedral barite crystals are of two different habits: (1) highly modified crystals of equant habit, with (110), (111) and (001) as prominent forms and (2) crystals of pyramidal habit with the unit bipyramid (111) as the dominant form, a very rare habit for barite.

*Other minerals.*—There are a few other minerals which occur in such small quantities they have not yet been identified. Some of the massive gray specimens are apparently homogeneous but prove on microscopic examination to be microcrystalline aggregates. Mineralogical literature is so full of descriptions of so-called new minerals based upon such material that the writer has refrained from an attempt to characterize these substances until better specimens can be obtained.

## Paragenesis of the Minerals.[3]

After the minerals of a rock or mineral deposit have been identified, the next thing to do is to determine the relations of the minerals to each other. This is often a

[2] This determination took only 15 minutes which is a testimony to the value of optical methods in determining minerals in fragments by means of the polarizing microscope. The writer had never seen ganophyllite before and had scarcely heard of the mineral.

[3] By this term I mean the relation of associated minerals, not simply the order of succession, which is only one phase of these relations.

difficult task, but it is equally important with the determination of the minerals.

The order of succession of the minerals of this manganese deposit is as follows: tephroite, hausmannite, rhodochrosite, pyrochroite, and psilomelane. The place of barite cannot be fixed definitely, but it seems to be earlier than the rhodochrosite. It probably occurs in several generations.

Tephroite is undoubtedly the earliest formed mineral present. It was probably abundant at one stage in the history of the deposit but is now present as residual specks. The alteration products of the tephroite are indefinite, ill-defined substances to which no name can be assigned.

Hausmannite, although occurring in euhedral crystals, was probably formed later than the tephroite, for vein-like areas of hausmannite surround and extend into areas of tephroite and there is no evidence of more than one generation of hausmannite.

Rhodochrosite is certainly later than the tephroite and hausmannite, for it occurs in veinlets cutting these minerals. It is often associated with barite and replaces the barite.

The pyrochroite is a relatively late mineral, for it occurs as a replacement of hausmannite and is common in euhedral crystals along seams. It is also later than a part at least of the barite.

The pyrochroite in turn yields to a brown hydrous manganese oxide which may possibly be the amorphous equivalent of manganite.

Finally the psilomelane was formed as a crust on the exterior of the bowlder probably after it was detached from its place of origin.

The above order of sequence seems reasonable in view of the fact that most of the minerals show a general increase in the state of oxidation of the manganese from the early to the late stages. In the tephroite we have the manganous state ($2MnO.SiO_2$); in hausmannite, we have an intermediate condition ($Mn_3O_4$), and finally in psilomelane a still higher state of oxidation ($MnO_2$).

The bowlder undoubtedly represents a block detached from its original location in the hills above, in some past, probably remote, period. With the exception of the barite it contains no gangue minerals, although lacking

in chalcedony and quartz. It is probably of Franciscan age, as are all the other manganese deposits of the Coast Ranges. The occurrence of hausmannite at a mine in San Luis Obispo County[4] and an undescribed occurrence of tephroite near Mount Diablo both in rocks of Franciscan age gives credence to this belief. Franciscan cherts and jaspers outcrop two to three miles east of the spot in which the bowlder is located. Several manganese deposits are found here but as far as examined they are different mineralogically from the so-called meteorite.

The typical occurrence of tephroite and hausmannite is in contact-metamorphic deposits. No limestone is present in the vicinity of Alum Rock Canyon and none was found in the bowlder. Limestones of Franciscan age are known at various places in the Coast Ranges but they are unmetamorphosed.

Although some doubt is attached to the original occurrence of this manganese ore, the presence of tephroite and hausmannite points to the high-temperature nature of the deposit. The rhodochrosite is undoubtedly a hydrothermal mineral and the psilomelane doubtless was formed by meteoric waters at a very late period. The pyrochroite is intermediate in age between the rhodochrosite and the psilomelane. Was it formed by meteoric waters or by hydrothermal solutions? This question cannot be answered definitely, but it is believed to have been formed at a late hydrothermal stage. It is altered to a later hydrous manganese oxide and so is unstable under oxidizing conditions. In fact specimens alter when exposed for several days. The presence of a large amount of water [$Mn(OH)_2$; $H_2O = 20{\cdot}3$ per cent] is no proof that a mineral is formed by meteoric waters.

Such is believed to be the essential history of this interesting deposit or rather remnant of a deposit, though a number of questions can not be settled for lack of sufficient data. The existence of this bowlder makes it probable that some, if not many, of the manganese deposits of the Coast Ranges of California are of high temperature hydrothermal origin. The prevalence of psilomelane may be accounted for by subsequent alteration of the hydrothermal minerals by meteoric water.

Stanford University, California,
September, 1919.

[4] Bull. 76, California State Mining Bureau, p. 14, 1918.

ART. XXXII.—*Orthogenetic Development of the Costæ in the Perisphinctinæ;*[1] by MARJORIE O'CONNELL, Ph.D.

The word orthogenesis is derived from the Greek ὀρθός, straight, and γένεσις, production, and means simply development or variation in a definite direction. There are at present two different conceptions of the meaning of this term, one being that orthogenesis is a fact made known to us by observation, the other that it is a theory to explain observed facts. A few quotations will illustrate the divergence in thought in these two fundamental concepts of a single term.

Eimer, in his paper on 'Orthogenesis and the Impotence of Natural Selection,' has made a careful distinction between the fact and the cause of orthogenesis. He was the first to bring the term into general use and it is, therefore, important to know exactly what he meant by it. He says: "The translation of definitely directed development (*bestimmt gerichtete Entwicklung*) into the word 'orthogenesis' was first employed by Wilhelm Haacke in his book *Gestaltung und Vererbung* in 1893, and as it is very expressive, I have adopted it for my own use."[2] "Orthogenesis," Eimer states, "shows that organisms develop in definite directions without the least regard for utility through purely physiological causes as the result of *organic* growth."[3] Orthogenesis he defines elsewhere as "the fact that the transmutation of the animal world takes place, not as Darwinism and the advocates of 'omnipotent natural selection' (Weismannian Pseudo-Darwinism) assume, accidentally in numerous and even widely diverse directions, but systematically and conformably to law in only a few directions."[4] Eimer not only adduced a wealth of illustration in support of his belief in the universality of the law of orthogenesis, but he attempted to formulate the causes and it was here that he came into conflict with the fol-

[1] This paper is based on material in the collections of the Department of Geology and Invertebrate Paleontology of the American Museum of Natural History and was prepared while the author was an assistant in the department, but the researches were carried on and this paper was written outside of official hours. The material was collected in Cuba by Mr. Barnum Brown of the Museum and is described in a forthcoming paper.

[2] Eimer, I. H. Theodor, 1898. Orthogenesis and the Impotence of Natural Selection, p. 19.

[3] Loc. cit., p. 2.

[4] Loc. cit., p. 20.

lowers of Darwin and Weismann, for he came out strongly against the potency of natural selection in the formation of species, considering it only as a process which "may remove what is downright injurious" and "may preserve what is useful" but which is always subordinate to orthogenesis. Furthermore, he advocated the inheritance of acquired characters as a necessary outcome of the operation of the law of orthogenesis and expressed the belief that "the causes of definitely directed evolution [i. e. orthogenesis] are contained . . . in the effects produced by outward circumstances and influences such as climate and nutrition upon the constitution of a given organism."[5]

It is not our purpose to enter into a discussion of these causes; we are seeking only to discover how the term orthogenesis should be used, and we see that Eimer, who first gave it prominence, distinguished between the law and the causes of orthogenesis or definitely directed evolution. Later authors, however, have usually confused the two.

Professor Grabau in his 'Studies of Gastropoda' has followed Eimer's usage, regarding orthogenesis as an observable method of development, and he states that: "Orthogenetic variation may be defined as progressive variation along definite or determinate lines."[6]

Professor Lull, on the other hand, in his book on 'Organic Evolution' says: "Orthogenesis . . . is the theory that variations and hence evolutionary change occur along certain definite lines impelled by laws of which we know not the cause."[7] Finally, Professor Morgan in his 'Critique of the Theory of Evolution' includes the unfolding principle as one of the "four great historical speculations" concerning evolution, stating that "it is little more than a mystic sentiment to the effect that evolution is the result of an inner driving force or principle which goes under many names such as Bildungstrieb, nisus formativus, vital force and orthogenesis."[8]

From these diverse expressions of opinion it is clear

[5] Loc. cit., p. 22.

[6] Grabau, A. W., 1907. Studies of Gastropoda. On Orthogenetic Variation in Gastropoda, Am. Naturalist, vol. 41, no. 490, p. 607.

[7] Lull, R. S., 1917. Organic Evolution, p. 175. (Macmillan Company.)

[8] Morgan, T. H., 1916. A Critique of the Theory of Evolution, p. 34. (Princeton University Press.)

that the term orthogenesis has been used by some writers to describe certain observed phenomena and by others to explain the origin of those phenomena. It is for this very reason that so much confusion has arisen and many who cannot see in orthogenesis a cause of evolution deny its existence as a mode of development. If at the outset, then, we distinguish between the fact or law of orthogenesis and a possible, and as yet undiscovered, cause of orthogenesis, the matter is greatly simplified and we lay claim to nothing but what we can see. It is true that Eimer believes that he has discovered the cause of orthogenesis, but his statements are open to criticism and there is no question that his data and observations are capable of other interpretations than the ones which he has given. What we cannot deny, however, is that he did bring together many excellent illustrations of the law of orthogenesis whether or not we believe in the explanation which he offered.

Considering, then, that orthogenesis is to be applied to facts, to observable phenomena, we must make one further restriction and state that the observations made must be of successive changes, either in the growth of an individual, that is, in ontogeny, or in the evolution of the race, that is, in phylogeny. This idea of succession is bound up in the very definition of orthogenesis and must not be lost sight of.

There are four fields in which observations may be made to a greater or less extent in carrying on orthogenetic studies, namely, those of experimental and observational biology, embryology, vertebrate paleontology and invertebrate paleontology.

It is at once apparent from our restricted definition of orthogenesis that the zoologist seldom has the facts of orthogenesis presented to him in his studies, for he deals with individual adults, in which he sees only single isolated stages in the ontogeny, and he deals with living forms, having thus nothing to do with phylogeny, except in so far as this is presented in a single chronofauna. The experimental zoologist, or genetecist, concerns himself neither with successive changes in the development of the individual nor with the changes through geologic time in species, genera or phyla and he, therefore, never has presented to him the data for orthogenetic studies. The observational biologist may, to a limited degree,

observe phyletic trends when he considers a species in its geographic distribution or studies the variations in different characters in successive generations throughout a period of years. In the case of geographic distribution, if the zoologist starts from a given center of distribution and is able to follow out in unbroken lines the variations which arise in passing from the point of origin to provinces successively further removed, then he may, and theoretically should, observe orthogenetic changes. The practical difficulty frequently presents itself of determining to his own and others' satisfaction what was the center of distribution and which was the fundamental primitive species whence the numerous adaptively radiating variations were derived. In the study of determinate variations in a single species the zoologist probably has his best opportunity to see the facts of orthogenesis. As an instance of this method of approach may be cited the observations made by Kellogg and Bell on the flower beetle, *Diabrotica soror,* collected from the campus of Leland Stanford University. Series of a thousand individuals each were studied and their variations over a period of seven years were recorded and it was found that in that time there had been a very definite change in the prevalence of one type of color pattern on the wings over another. In such a case as this the zoologist, while seeing nothing of ontogeny, yet has the advantage of the time element which is essential in the study of phylogeny, but the time at his disposal is so short that he can observe only comparatively insignificant variations in characters sufficiently mutable to show a recognizable change during a period which must, after all, be considered as only an instant when compared with the hundreds of millions of years during which evolution has been producing the complex types which the zoologist observes. Yet, however small such variations are, if they show a definite direction the fact of orthogenesis is clearly demonstrated. Obviously the facts of phylogeny as a whole or even in any appreciable amount are never visible to the zoologist who is mortal.

The embryologist likewise is cut off from the broad facts of phylogeny because he must of necessity deal with living forms. Furthermore, although he has before him the entire ontogeny of the individuals of the present, he, as a rule, elects to look at only the embryonic stages,

passing over as of little or no importance the complete epembryonic development. It is true that the embryologist sees successive changes in growth and that he can make certain general comparisons, but, as is well known, the history which he reads is so abbreviated, so many chapters are lost through condensation and elimination, that he catches but an evanescent glimpse of this or that ancestral condition as the pages pass rapidly before his gaze. Furthermore, he makes his comparison not so much between entire embryos of various types, as between the different organs of embryos higher or lower in the scale of life. Thus he traces the homologies of the fore-limbs in the embryo of a bird, the bat and man, he finds that the heart in mammals in the course of its embryonic development passes through fish, amphibian and reptilian stages, but in these and all similar cases comparisons are made between stages of development of organs not organisms and the recapitulation observed is so general that we see the same kind of embryonic succession in all mammals, for instance, with variations produced more by what is left out of the history than by what is added, for each organism, if it could give a complete recapitulation of its ancestral characters, would have to show all that the paleontologist already knows and all that he hopes to know as well as what he never will know. Therefore, in any given embryo we see a few selected pages, but it is clear that orthogenetic trends will be entirely obscured, since such directions are seen in individuals, in species, in genera but not when we pass from phylum to phylum, from fish to reptile, to amphibian, to mammal.

The third field open for orthogenetic studies is that of vertebrate paleontology. Here one may observe successive changes in time and may work out evolutionary series which in many cases show orthogenesis or, as Professor Grabau has called it, ortho-phylogeny, in contradistinction to ortho-ontogeny. As a rule the vertebrate paleontologist deals with adult individuals and for any species he may know nothing of the young and sub-mature stages of development. In other words, he may arrange an entire phyletic series without knowing anything about the ontogeny of the species in that series. A knowledge of the ontogeny must always be fortuitous, depending upon the finding in a single place of a large

number of skeletons ranging in age from young to adult but all representing one species. Even in such a rare and happy case there is no proof that the young individuals are actually the immature forms of the adults found in the same place, however perfect a gradation in characters and proportions may be shown in the specimens, for parallelism in the development of genetically unrelated species may so obscure the true diversity in origin that an ideal series may be arranged which unfortunately has no other value than its diagrammatic clearness. It is even worse when the young individuals of a species are found in a locality at some distance from that where the adults occur. When we consider the vicissitudes attending the preservation of vertebrates, particularly terrestrial and aerial forms, when we think of the many groups which must at all times have been branching off from the main lines and have been developing progressively and retrogressively with changing proportions and newly appearing characters, the chances are rather against there being any necessary genetic relationship between a young individual found at one locality and an adult found at some distance, even if at the same horizon. With organic and inorganic factors working, it would seem, for the very purpose of obscuring genetic relations, the vertebrate paleontologist certainly has no enviable task in trying to decipher ontogeny. We see, then, that in this field the illustrations of orthogenesis must be sought almost wholly in phylogeny and it is here that we find such celebrated series as those of the horse, the elephant and the titanotheres. Yet is it not true that in all of these cases there are elements of doubt? We may not go so far as does Professor Morgan who says that the paleontologist chooses to arrange his specimens in certain series, but that they might just as well be arranged in some altogether different fashion. Thus, Professor Morgan has obtained in a single generation of flies what appears to be a perfect orthogenetic gradation of eye color which makes a good series with every transition shown from white to red and yet this is due simply to certain slight differences in the chromosomes which produce in a single batch of flies variations indicating no definite direction in development such as a paleontologist would think he had if he found a series showing similar slight gradations in a given character.

We will not go so far, I say, as to agree with Professor Morgan that the vertebrate paleontologist could juggle his specimens and arrange them to show anything he desired to, but we must admit, I think, that there are many chances to go wrong when one makes up a genetic series, say from a dozen adult specimens occurring from Eocenic time to the Pleistocenic, and that even if these dozen individuals show certain definite trends in development such as the increase in length of a horn, the loss of a toe, the addition of cusps on the teeth, there will always remain the question: are not these dozen specimens simply individuals belonging to many lines, some of which may even have become extinct, and do they not give a general picture of the kind of development of the race as a whole rather than a genetic series? For instance, Professor Osborn has pointed out that in the titanotheres the actual continuity of the series "is broken by the extinction of one branch and survival of another. It is a continuity of *character* rather than of lines of descent."[9]

If we turn to the fourth field of orthogenetic study, that of invertebrate paleontology, we find that both phylogeny and ontogeny are available in most cases. It is true that the ontogeny of the crustacea and certain smaller groups is nearly as difficult to study as that of the vertebrates, because the individuals do not retain the record of their early developmental stages, but in the molluscs, corals and brachiopods, the shell or other hard structure preserves the complete record of the life history of the individual from the earliest epembryonic stage to the time of the death of the animal, which was normally in late maturity or old age. In many cases, where the material is well preserved, one may even see the last embryonic stage, so that one may enter, if only a short way, into the field of the embryologist. The invertebrate paleontologist is also fortunate in having large numbers of individuals of a single species to study. He may collect literally a thousand specimens of one species at a given spot and horizon, and then he may collect at successive horizons, going upward inch by inch collecting quantities in each stratum and thus he may work out with a certainty hardly to be questioned what was the nature of the changes which took place in that

[9] Osborn, H. F.: Origin and Evolution of Life, p. 264.

species at each level, that is, what varieties arose (in the Waagen sense), and he may trace also the changes in time from level to level, that is the mutations.

In addition to these geographic and geologic data in phylogeny he has the entire life history of each individual so that he may pass from the details of ontogeny to the generalities of phylogeny in accordance with the law of recapitulation. But this law of recapitulation has to the invertebrate paleontologist a very different meaning from that which it has to the embryologist and zoologist as Hyatt, Jackson, Smith, Grabau and others have shown. The embryologist finds that there is a general similarity between the adults of certain lower forms and the embryonic stages of higher forms in living organisms, but the invertebrate paleontologist compares the entire epembryonic development or the stages between the embryo and the adult step by step with the adults in earlier geologic horizons, finding in the life history of a single individual an epitome not alone of the development of the genus, but of the entire phylum. These differences in the viewpoint of the law of recapitulation are well known, I merely repeat them here because as we understand recapitulation so do we understand orthogenesis. The invertebrate paleontologist ever approaches ortho-phylogeny in the light and under the guidance of ortho-ontogeny, dealing with the minute changes in the life history of the individual and at most arguing for orthogenetic development in a single phylum, as in corals or ammonites, but never invoking it to cover the method of development from one phylum into another.

Of all the invertebrates the ammonites offer, perhaps, the best opportunities for orthogenetic studies because of their abundance, their comparatively rapid evolution, their complexity in structure, involving as it does a large number of variable characters, and their mode of growth. Because of the coiling of the ammonite shell the early stages are always accessible in well-preserved material, and by separating off the successively earlier and earlier whorls one may ascertain what were the various steps in the life history of any single individual. One may thus follow out the entire ontogeny and from this one may, with reasonable certainty, predict what was the phylogeny of the genus or family to which the species under study belonged.

I have taken a single species among the ammonites and have studied the ontogeny in a single specimen. The species is a new one and belongs to the Jurassic ammonite fauna of Cuba collected by Mr. Barnum Brown and now in the American Museum of Natural History. The holotype of the species, *Perisphinctes cubanensis* O'Connell, shows orthogenetic development in several shell characters, but I have selected as the most striking illustration that of the development of the costæ. The entire method of growth of the costæ will be discussed in a forthcoming paper, but the particular illustration of orthogenesis is amply shown on the last two whorls of the holotype. The costæ are arranged in groups of three which consist of one long costa extending from dorsum to venter of the whorl and two short costæ which extend across the venter and about a third of the way dorsad on the whorl. A generic characteristic of *Perisphinctes* is the presence, at repeated intervals on the conch, of constrictions or grooves which appear as interruptions to the normal costal arrangement. In *Perisphinctes cubanensis* there are from three to five groups of costæ between every two constrictions or sphincters (S. in fig. 1). In each intersphincterial sector of the shell the costæ show a progressive mode of development, each group of three costæ being a little in advance in two characters over that just preceding. The simplest arrangement of the three costæ consists of a long costa extending from venter to dorsum, a short one attached to the long one and the third branching off from the first at a point slightly lower than the point of attachment of the second costa; the second and third costæ are of equal strength and both are weaker than and not so thick as the first. This primitive condition is shown in the earlier whorls of the species and is very nearly approached in the first triad illustrated in fig. 1 where, however, the third costa is slightly separated from the first. Starting with this primitive costal grouping the second set of three (fig. 1) shows the greatest strength in the second costa with the first and third of equal strength and both attached to the second costa and bending towards it, one forward the other backward, so that the three appear likes the tines of a fork. The next group of three shows the greatest strength still in the second costa, the first being now separated off as a free

costa while the third is still attached. The fourth group shows the strength in the third costa, one free and two directed towards three. The costæ at this point are interrupted by a constriction beyond which the costal arrangement instead of continuing the trend shown in the preceding intersphincterial sector shows a retrogression. But the first triad of costæ does not show the same

FIG. 1.

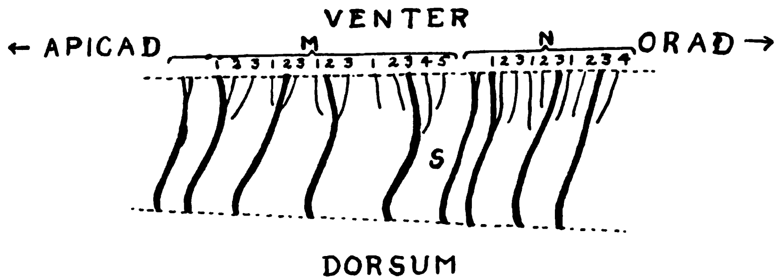


FIG. 1.—Arrangement of costæ on last half of fifth volution of the holotype of *Perisphinctes cubanensis* O'Connell. S. constriction or sphincter marking interruption in regular costal development.

FIG. 2.

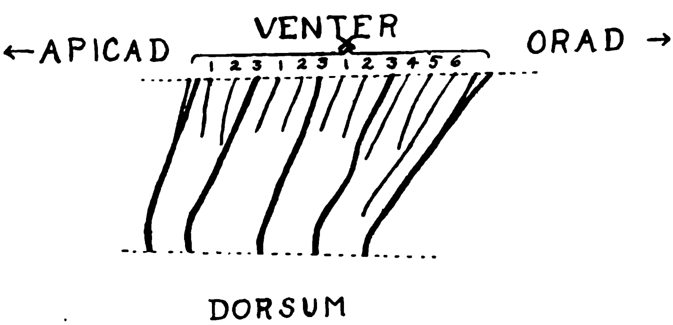


FIG. 2.—Arrangement of costæ in early part of sixth volution of the holotype of *Perisphinctes cubanensis* O'Connell. The orad migration of the strong costa is shown, as well as the mode of development of free "intercalated" costæ.

arrangement as the first triad in the preceding sector; it marks instead a stage intermediate between the first and second groups. Throughout the second sector the groups of three are slightly in advance of the same groups in the first one, but the mode of development is identical, there being a forward passage of the strength of the costæ and a concomitant freeing of the costæ.

Skipping about a quarter of a volution, we may note the costal arrangement on the sixth whorl from 6¼ to 6½ volutions (fig. 2). In the first triad in this intersphincterial sector the greatest strength has already passed to the third costa, one is free and two free but still directed toward three; it corresponds approximately to the stage of development shown in the second group of sector N, being, however, a little more accelerated. The second triad in X is about correlative with the third in N. The third triad in X immediately precedes a constriction and has certain special features which need not be discussed here. Thus the beginning of each intersphincterial sector shows the costæ at a more advanced stage of development than they were at the beginning of the preceding sector and the end of each sector is more advanced than the end of the preceding one. The costæ develop in a definite way according to law but there is not uninterrupted progress throughout the life of the individual; rather is there a constant repetition of what has been done before by the animal and an addition of one step more each time, so that the final adult stage shows a condition far in advance of the youthful stage but the result is obtained only by progress to a certain point, then an interruption and a new beginning with progress again a little beyond the point reached before the interruption, and so on.

This mode of costal development holds not only in this species but in many others and the stages shown in the single individual described are found to be characteristic of the adults of earlier geologic representatives of the genus, and in these the costæ develop in the same way as in the young *P. cubanensis*. Thus the definite direction of development of the costæ in the single specimen of this species is not a matter of individual growth but is some tendency inherent in the organism which leads to the same type of development in related species and in ancestors and descendants throughout Middle and Upper Jurassic time.

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New York City.

ART. XXXIII.—*Heterolasma foerstei, a New Genus and Species of Tetracoralla from the Niagaran of Michigan;*[1] by G. M. EHLERS.

The type specimen of this interesting coral, *Heterolasma foerstei,* was collected from a cherty, brown, magnesian limestone of thin, uneven-bedding. This rock outcrops at the top of a very low, eastward-facing escarpment about half a mile south of Gould City, Mackinac County, Michigan. This limestone, now placed by the Michigan Geological and Biological Survey in the Manistique formation of the Niagaran of Michigan, in the writer's opinion should be correlated with the Upper Coral Beds of Wisconsin and the Lockport of Ontario and New York.

The shape of the corallum, which is silicified and preserved in a fragmentary condition, was that of a short cone, with the upper part widely expanded horizontally (see fig. 1). The side of the corallum adjacent to the cardinal septum has a slightly greater curvature.

The epithecal covering of the outer surface is annulated by low ridges and shallow grooves (see fig. 2). Fine, close-set, concentric lines, probably representing lines of growth, are obscurely shown on a few of the better preserved portions of the epithecal surface.

Stout radiciform processes occur at irregular intervals (see figs. 1 and 2). Some of the better preserved ones exhibit a double tubular construction, produced by the downward extension of the theca within the epitheca. The two tubes seem to have been normally separated throughout most of their length. This separation of the thecal and epithecal tubes is clearly shown at the broken end of the process indicated as $r^1$ on fig. 2. The same structure is indicated in two other processes, $r^2$ and $r^3$ fig. 2, although the inner and outer tubes are much obscured by deposits of chalcedony in the spaces between them.

The extension of the theca into the radiciform processes has resulted in the formation of more or less circular openings in the wall of the calyx, which interrupt the continuity of some of the septa. Several septa are

[1] Published with the permission of the Director of the Michigan Geological and Biological Survey.

locally bent down into these openings or deflected towards them. The opening of the radiciform process $r^3$, fig. 2, shown at $r^3$, fig. 3, is situated on the line of a lamelliform, secondary septum, breaking its continuity. The terminal portion of the septum to the left of $r^3$, fig. 3, is depressed towards this opening. Because the side of the opening adjacent to this part of the septum is covered by a small, incrusting cham-coral, *Halysites catenularia,* the possible downward extension of the septum into the inner tube can not be seen. The small, curved part of the septum, shown in fig. 3 between the opening and the broken edge of the calyx, is bent down a considerable distance into the inner tube. To the left of this segment of the lamelliform septum is a small detached portion of a denticulate, tertiary septum, which is deflected towards the opening of the radiciform process.

Fig. 1.

Fig. 1.—A side view of the type specimen of *Heterolasma foerstei,* indicating the shape of the preserved corallum. Natural size.

Other septa are similarly interrupted and deflected at the openings of the radiciform processes $r^2$ and $r^1$, fig. 2, shown respectively at $r^2$ and $r^1$, fig. 3. The opening at $r^1$ is situated upon the line of a denticulate septum, whereas those at $r^2$ and $r^3$ are located upon the lines of lamelliform septa. The large opening at $r^0$, fig. 3, toward which a few septa are depressed and deflected, was probably formed by the breaking off of a radiciform process.

The complete calyx probably had a circular margin and was very wide and relatively shallow. Its diameter is estimated as having been about 130 millimeters and its depth between 10 and 15 millimeters.

The septa are very short and exhibit a bilateral symmetry. The four principal septa are well shown with

the exception of the cardinal one. This septum is poorly indicated in the fossula, which is indicated on both lower and upper sides of the specimen (see *f*, figs. 2 and 3). A fissure, probably formed by the solution of the cardinal septum, is readily seen in the central part of the fossula

FIG. 2.

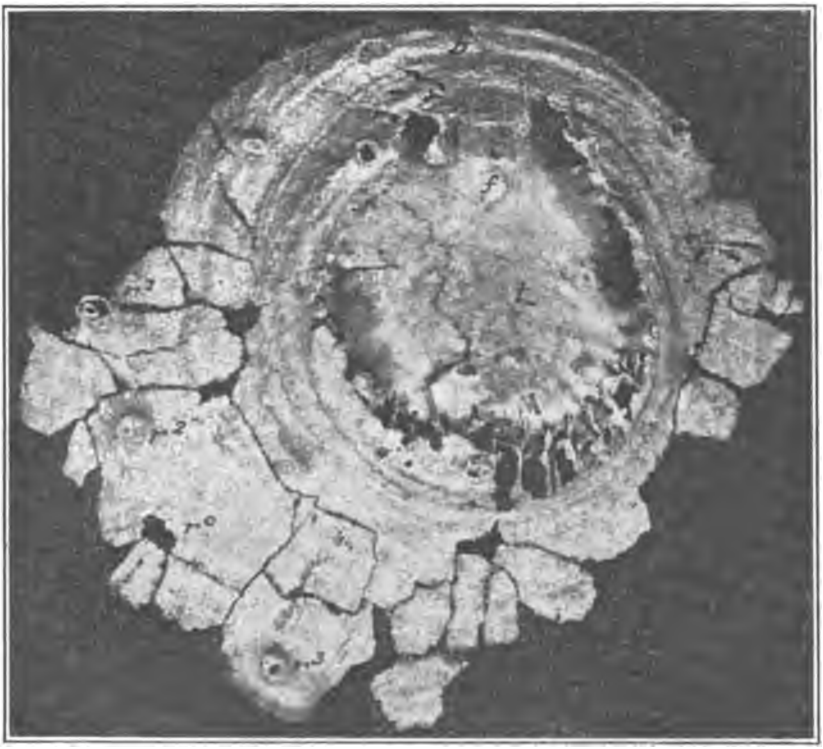

FIG. 2.—View of the type specimen of *Heterolasma foerstei* from below, showing the character of the outer surface of the corallum, double tubular construction of the radiciform processes, a tabula and the position of the fossula. Natural size.

as shown on the lower, broken side of the specimen. A part of the septum may be represented by a low, sharp-crested ridge that extends towards the interior of the coral, for a distance of 3 millimeters, from the inner end of the fissure. The cardinal septum is not definitely recognizable in the fossula on the upper side of the corallum. Within the fossula, which would exhibit con-

siderable width except for its partial covering by tabulæ, is a small, irregular wedge-shaped protuberance, which is shown on fig. 3 above *f* and to the right of a deep, narrow and much elongated depression. The thin covering of the protuberance consists of a folded portion of the incomplete and much fractured tabula indicated as $t^2$, fig. 3; the space beneath the folded portion of tabula is more or less filled with colorless, crystalline quartz. A narrow, obscure band of light-gray, crystalline quartz, which is in contact with the inner side of the tabula on the left side of the protuberance, extends from the wall of the corallum to the inner surface of the tabula above. This strip of gray quartz may represent the cardinal septum for the reason that it occupies the position of this septum in the central part of the fossula. Further evidence that the band of quartz may represent the cardinal septum is indicated by its apparent continuity with the base of this septum, a small part of which seems to be split by a break (*b*, fig. 2) in the wall of the corallum. A counter septum (*c*, fig. 3) and two alar septa (*a*, fig. 3) are readily distinguishable in the calyx and on the lower side of the specimen. The secondary septa are lamelliform and show no denticulations on their inner edges. Forty-four of these septa are shown in the calyx, eleven occurring in each quadrant. A septum is doubtfully indicated on each side of the ill-defined cardinal septum. On the lower side of the specimen, eleven septa also occur between the counter and each alar septum but only ten between each alar septum and the cardinal one. The two or four extra septa, shown in the calyx between the alar septa and the center of the fossula, are inserted at a point above the lower surface of the specimen. Midway between the secondary septa are very low, tertiary septa, each of which bears a single row of sharply pointed denticulations upon its inner margin (see fig. 3). Between these denticulate septa and the lamelliform septa are very low, obscure septal ridges, representing quaternary septa.

The central part of the calyx and the interior of the corallum below it are occupied by wide, slightly concave tabulæ, which curve sharply down between the lamelliform septa and unite with the wall of the corallum. Two nearly complete tabulæ are shown in the specimen (see *t* and $t^1$, figs. 2 and 3). Overlying the upper one in the

central part of the calyx is a fractured portion of a third tabula. The marginal remains of this tabula and possibly another are partly preserved between some of the lamelliform septa (see fig. 3). Other tabulæ may be present in the space between the two nearly complete tabulæ.

The tabulæ are variously modified in the interseptal

Fig. 3.

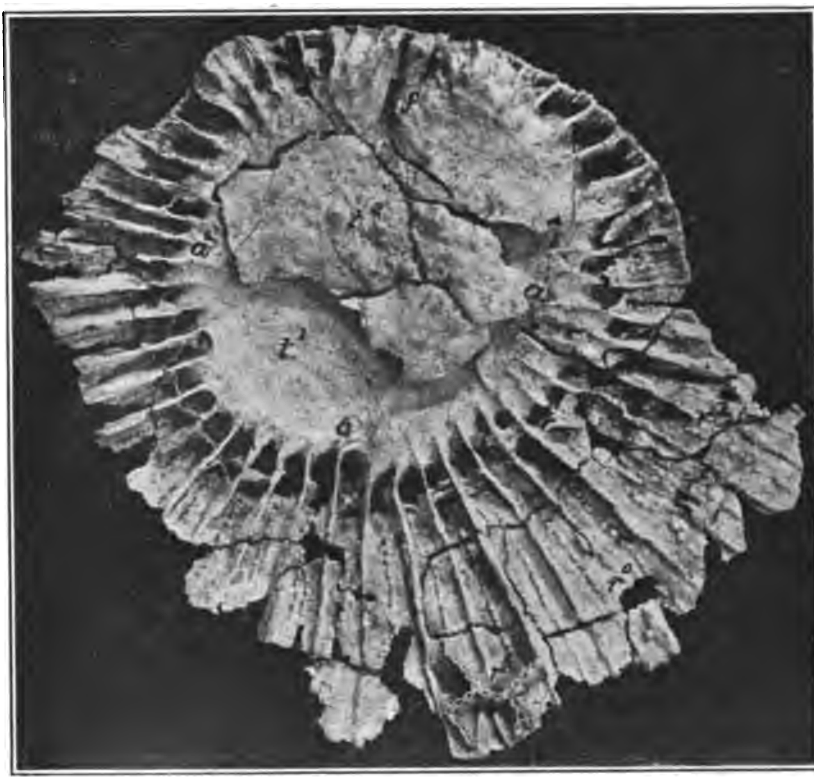

Fig. 3.—Calycinal view of the type specimen of *Heterolasma foerstei*, showing the different kinds of septa, tabulæ and the openings of the radiciform processes. Natural size.

spaces. They extend upwards to meet the sides of the septa; as a result, the upper surfaces of the tabulæ in each interseptal space become concave (see $t^1$, fig. 3). Frequently, the tabulæ are much depressed towards the angles made by the junctures of the lamelliform septa and the wall of the corallum, thus forming small, irreg-

ular-shaped funnels. In one interseptal space, a funnel is formed by the depression of a tabula towards one of the angles made by a denticulate septum and the wall of the corallum. A few funnels are produced by the depression of the tabulæ towards points on the wall that are intermediate between the lamelliform and denticulate septa.

The appearance of simple dissepiments is sometimes produced by the branching of the tabulæ near the wall of the corallum. True dissepiments, however, probably never were formed.

The paleontological museum of the University of Michigan contains another specimen of *Heterolasma foerstei,* which was found by Dr. Carl Rominger near the village of Detour, Chippewa County, Michigan.

The specimen, which, with little doubt, was collected from the Manistique strata, is silicified and more poorly preserved than the type specimen. Most of the lower, short conical part of the corallum and all of the horizontally expanded upper part have been broken off.

The broken and somewhat compressed specimen differs in structure from the type specimen only in the preservation, number and arrangement of certain septa. The cardinal septum, which is poorly indicated in the type specimen, is well shown in the calyx of this specimen. The positions of the two alar septa and the counter septum are also more or less well indicated. Fifty-two lamelliform, secondary septa seem to have been present originally; eleven are shown in each of the counter quadrants, fifteen in one cardinal quadrant and fourteen in the other. A fifteenth septum is not shown in the last mentioned cardinal quadrant, owing to its probable removal with a small part of the wall of the corallum. The tertiary, denticulate septa and the low, quaternary ones are more or less poorly preserved, owing to solution and silification of the corallum.

*Zaphrentis patens Billings,*[2] which occurs in the Anticostian (Jupiter River) strata of Cormorant Point, Anticosti, seems to be congeneric with *Heterolasma foerstei.* This relationship is indicated by the more or less close similarity in the shape of the coralla and in the character of the septa and tabulæ.

[2] This species was described first by Mr. E. Billings (Can. Nat. Geol., new ser., vol. 2, p. 430, 1865) and later by Dr. L. M. Lambe (Contr. Can. Pal., Geol. Surv. Canada, vol. 4, pt. 2, pp. 119-120, 1901).

The holotype[3] of *Heterolasma patens* differs from *Heterolasma foerstei* in having a smaller number of lamelliform, secondary septa (32 or 34), in the much greater extension of the secondary septa toward the center and in the apparent absence of low quaternary septa and radiciform processes. It is possible, however, that the holotype of *Heterolasma patens* may possess radiciform processes. These, if present, are not shown because the specimen is imbedded in matrix. If better preserved specimens of this species are found, showing *Heterolasma foerstei,* then the two species should be combined under the name *Heterolasma patens* (*Billings*). At this time, however, enough differences in structure between the Anticosti and Michigan specimens are known to warrant their separation as distinct species.

The genus *Heterolasma* seems to represent an aberrant departure from *Zaphrentis.* It differs from the latter genus chiefly in not having the septa reach the center of the corallum. In this respect, it resembles *Amplexus.* The genus *Heterolasma* is also characterized by its wide tabulae and its shape, which is that of a short cone with more or less horizontally extended margins. One of the most distinctive characters of this genus is the difference in the form of the septa. The name *Heterolasma,* which well indicates this character, was suggested to the writer by Dr. A. R. Foerste, in whose honor the writer takes great pleasure in naming the genotype.

University of Michigan,
Ann Arbor, Michigan.

[3] The writer is under obligations to Miss A. E. Wilson and Dr. M. Y. Williams of the Canadian Geological Survey for information relating to the structure and preservation of the holotype of *Heterolasma patens.*

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# SCIENTIFIC INTELLIGENCE.

## I. Chemistry and Physics.

1. *The Determination of Zirconium by the Phosphate Method.*—G. E. F. Lundell and H. B. Knowles of the U. S. Bureau of Standards have rendered valuable service to mineral analysis by a study of this method, originally devised by Hillebrand for the determination of the minute quantities of zir-

conium frequently found in ordinary rocks. While this method as described by Hillebrand was a satisfactory one for determining such quantities as from 0·02 to 0·2 per cent, there was doubt about the composition of the washed and ignited precipitate and, consequently, concerning the proper factor to be used for larger quantities of the precipitate, as well as in regard to other details of the determination.

The present authors recommend the precipitation by means of secondary ammonium phosphate added in excess to the extent of 10 to 100 times the amount calculated from the ratio Zr: $P_2O_5$, in a volume from 25 cc to 200 cc, according to the amount of zirconium present, up to 0·1 g. The acidity of the solution should be 20% sulphuric acid by weight. Hydrogen peroxide should be added to prevent the precipitation of titanium, 10 cc of this will do no harm. The temperature of precipitation should be cold or preferably 40-50°, and the time of standing before filtration should be two hours for larger amounts in excess of 0·005 g. and 6 hours longer for smaller amounts. The filtration should be made warm with decantation of the supernatant liquid, and the washing should be done with 5% ammonium nitrate solution in order to avoid hydrolysis and consequent loss of phosphoric acid. The precipitate should be ignited very carefully in a partly covered platinum crucible until filter paper carbon is destroyed, followed by blasting or its equivalent. The ignited precipitate has the composition $ZrP_2O_7$, requiring the factor ·4632 for $ZrO_2$. This method separates zirconium satisfactorily from iron, aluminium, chromium, cerium and thorium, and in the presence of hydrogen peroxide from titanium.—*Jour. Amer. Chem. Soc.*, **41**, 1801.

H. L. W.

2. *An Introductory Course in Quantitative Chemical Analysis;* by GEORGE MCPHAIL SMITH. 8vo, pp. 206. New York, 1919 (The Macmillan Company).—This book is a rather elaborate one for a laboratory manual, displaying many excellent features. The introductory part, besides describing the operations, present a considerable amount of appropriate theoretical matter in the line of physical chemistry. Practical courses in gravimetric and volumetric analysis are presented with very full and clear descriptions of the methods of procedure together with numerous instructive notes in connection with each exercise. A section of the book is devoted to stoichiometrical problems. A few examples of these are explained, and then 100 very instructive problems, without answers, are given. An extensive series of questions concerning the practical exercises is presented in another section. There are notes on the preparation of reagents, a list of apparatus for the student's desk, and tables of four-place logarithms and antilogarithms. There is also a table of atomic weights, but no gravimetric or volumetric factors are given.

It appears that the use of this text-book would undoubtedly furnish an excellent training for students in quantitative analysis, but it seems to the reviewer that while the exercises in volumetric analysis are satisfactory in number, the gravimetric exercises for practice are rather inadequate in number and variety for giving an entirely satisfactory course in this fundamental branch of the subject. There are only nine of these gravimetric exercises, including the determination of only ten elements.

Like several recent books on quantitative analysis this one should be criticized for advocating weighing by the use of long swings of the balance beam, since this method is theoretically less accurate and practically enormously more laborious than by the use of very short swings across the center of the pointer-scale. However, the author deserves praise for mentioning the "usual method" of weighing and admitting that it is "sufficiently accurate for ordinary analytical work," but his emphatic statement that the "zero-point" of the unloaded balance should be determined and "made use of" in each weighing is an astonishing one in view of the facts that ordinary analytical weighings are always made by difference and that the balance with proper care will not change its point of equilibrium during the time required to make the two weighings that are necessary to obtain this difference. H. L. W.

3. *Richter's Organic Chemistry.* Volume I., Chemistry of Aliphatic Series. Translated by PERCY E. SPIELMANN. Second (Revised) Edition. 8vo, pp. 719. Philadelphia, 1919 (P. Blakiston's Son & Co.).—This excellent and widely used, advanced text-book has appeared in three American editions, translated by Professor Edgar F. Smith of the University of Pennsylvania. Afterwards, in 1915, was issued an English edition, of which the volume under consideration is a revision. The changes that have been made in the present edition are mainly corrections of errors in typography. H. L. W.

4. *Notes on Qualitative Analysis;* by LOUIS AGASSIZ TEST and H. M. MCLAUGHLIN. 12mo, pp. 92. Boston, 1919 (Ginn & Company).—This text-book has been prepared particularly for the use of students in the special case where the subject is taken up before general chemistry is completed. Therefore a considerable amount of theoretical instruction bearing upon the qualitative processes is presented. Thus, in the introduction, solutions, equilibrium, reversible reactions, mass action, ionization, solubility product, hydrolysis, etc., are clearly and simply discussed, while throughout the book frequent explanations of facts upon theoretical grounds are put forward. It may be said that perhaps this attitude is carried somewhat too far, since there is no doubt that facts are the fundamental things and that theories have been derived from them—not facts from theories.

The course of analysis given appears to be very satisfactory. It is an excellent feature that many experiments are given where the student is compelled to find for himself what happens, as the results are not described. It is noticeable that the book gives very few chemical equations, but it is expected that students shall write each reaction. At the end of the book is a long list of questions, many of which are very excellent for making the student think, but, as the authors admit, some of them are rather difficult for the average beginner. H. L. W.

5. *The Chemistry and Manufacture of Hydrogen;* by P. LITHERLAND TEED. 8vo, pp. 152. New York, 1919 (Longmans, Green & Co., price $3.40 net).—We find here a very clear and interesting monograph on hydrogen gas, the use of which has enormously increased in recent years, not only in connection with balloons and air ships for war purposes, but also for use in the hardening of oils and in the direct combination with nitrogen to form ammonia according to the Haber process.

The book takes up the uses, discovery, occurrence in nature and chemical properties of hydrogen, then it deals very thoroughly and satisfactorily with the manufacture of the gas by chemical, chemico-physical and physical methods. Numerous drawings illustrate the pieces of apparatus, many patents are referred to, and much other useful information is given. The book may be recommended to all who desire to understand this important industry. H. L. W.

6. *Calculation of the Radiation Constants $c_2$ and $\sigma$.*—The theory of series spectral lines first developed by Niels Bohr has been improved and extended by Sommerfeld. The more complete form of the theory has also been tested, by Paschen, on the spectra of hydrogen and helium, and found to be verified in the minutest details. After the empirical determination of a universal constant $a$ and of a constant $B$ characteristic of each gas, the theory gives not only an accurate representation of the series spectra of both gases, but it also furnishes an explanation of the detailed structure of the discrete lines as well as a clue to the intensity ratios of the separate components of the lines. Furthermore, on the basis of the theory, accurate values for the specific charge of an electron and for Planck's quantum constant $h$ have been computed from $B_1$ and $B_2$. (The subscripts 1 and 2 refer respectively to hydrogen and helium.) Since the theory is extremely reliable,—at least when applied to the gases just named,—and as an exceptionally high degree of accuracy can be attained in the measurement of wave-lengths, it may be expected that other physical quantities derived from the theory and spectroscopic data will also be very dependable.

The radiation constants $c_2$ and $\sigma$ have been computed, in the manner suggested, from the values of $B_1$ and $B_2$ by F. HENNING: $c_2$ occurs in the numerator of the exponent of the Napierian

base in Planck's formula for the intensity of radiation from an ideal black body, and $\sigma$ is the multiplier of the fourth power of the absolute temperature as it occurs in the Stefan-Boltzmann law. The numerical values employed in Henning's computations were: $B_1 = 109677{\cdot}69 \pm 0{\cdot}06$, $B_2 = 109722{\cdot}14 \pm 0{\cdot}04$, $A_1 = 1{\cdot}008$ (the atomic weight of hydrogen), $A_2 = 4{\cdot}002 \pm 0{\cdot}002$ (at. wt. of helium), $c = 2{\cdot}9989 \times 10^{10}$ (velocity of light), $R = 8{\cdot}315 \times 10^7$ (molecular gas-constant), and $e = 4{\cdot}774 \times 10^{10}$ (electronic charge; Millikan). The final results were $c_2 =$ **$1{\cdot}432 \pm 0{\cdot}005$** cm. degree, and $\sigma =$ **$(5{\cdot}717 \pm 0{\cdot}052)$**$\times 10^{-5}$ erg. cm.$^{-2}$ sec.$^{-1}$ degree$^{-4}$. For sake of comparison, the weighted mean values of the best direct determinations are given as $c_2 = 1{\cdot}43 \pm 0{\cdot}01$ and $\sigma = (5{\cdot}67 \pm 0{\cdot}18) \times 10^{-5}$. The author concludes with the remark that: "The splendid agreement between calculation and observation lends additional support to the hypotheses of the quantum theory."—*Verh. d. Deutsch. Phys. Gesell.*, **9/12**, 81, 1918. H. S. U.

7. *Indices of Refraction for X-Rays.*—Up to the present time all experimental attempts to detect the refraction of various bodies for *X*-rays have failed signally, doubtless because the indices of refraction differ from unity by extremely small amounts. The question as to whether it is possible to determine these indices experimentally is discussed briefly in a paper by A. Einstein.

The author's attention was drawn to this problem by some photographs that were sent to him by A. Köhler and that exhibited a peculiarity which is said to have baffled explanation. "The positives,—chiefly representing human limbs,—showed at the contours bright borders about 1 mm. wide in which the plates appeared to have been illuminated more strongly than in the surrounding regions outside of the geometrical shadows." Einstein expresses the opinion that the phenomenon in question is due to total reflection. Incidentally, it may be remarked that he does not mention the possibility of secondary radiation. In any event, the following considerations of Einstein merit the attention of experimental physicists.

The difficulty in determining $n$ depends upon the fact that, according to the classical theory of dispersion, $n-1$ should be of the order of $10^{-6}$. It is however easy to see that at almost grazing incidence total reflection of a detectable amount must obtain. Suppose $n<1$, say $n = 1-\epsilon$. Using the complements of the angles of incidence and reflection, Snell's law takes the form $\cos\psi = n \cos\psi'$. Retaining only the first two terms of the series expansion of the cosine, and substituting $1-\epsilon$ for $n$, it follows that $\epsilon = \frac{1}{2}(\psi^2-\psi'^2)$. The limiting angle $\psi_0$ of total reflection is determined by the condition $\psi' = 0$, hence $\psi_0 = \sqrt{(2\epsilon)}$ approximately. If $\epsilon$ is $10^{-6}$ then $\psi_0$ will be of the order of 0·0014 radian, or about 5 seconds of arc. This magnitude

should lie within the confines of experimental possibility. A similar argument applies in case it should happen that $\epsilon$ is negative.—*Verh. d. Deutsch. Phys. Gesell.*, **9/12**, 86, 1919.

H. S. U.

8. *The General Polarization Surface.*—When light falls upon a plane mirror,—the material of which is single refracting and does not exhibit metallic absorption,—the completeness of polarization will be a maximum when Brewster's condition $i = \tan^{-1} n$ is fulfilled. In general, it is not possible to produce artificially a beam of light having all of its rays strictly parallel, and therefore a wide beam of completely plane polarized light cannot be obtained by reflection at the surface of a plane mirror, even when monochromatic radiation is employed. In particular, the limited cone of rays of circular right section which can enter the eye of an observer, whose line of vision is directed obliquely toward a polarizing plane mirror, will not give a uniform field of view when the analyzing apparatus is set for extinction. As a matter of fact, under certain conditions of incidence, the field will be crossed by dark bands having the shape of conic sections. The concave sides of the conics will be turned toward the observer. The major axes of the conics will lie in the meridian plane of the reflected solid cone of rays, that is, the plane determined by the axis of the cone (line of sight) and the perpendicular dropped from the center of the pupil upon the plane of the reflector. The arcs nearest to the observer will be elliptical in form while those more remote will be hyperbolic, a single parabola falling between the two sets of loci just mentioned. Since the angular aperture of optical analyzers rarely exceeds 30° or 40°, and as the polarizing angle of glass mirrors is usually from 56° to 60°, the parabolic arc will be outside of the field of view so that hyperbolic arcs only will be observable.

By suitably curving (by empirical methods) the surface of the mirror Reuter has constructed cylindrical reflecting polarizers giving wide uniform fields of view. The curvature of the cylinder will depend, of course, upon the index of refraction and upon the angle of the cone.

The theoretical form of the surface which will produce the most uniform field, under given conditions, has been investigated mathematically by Felix Jentzsch-Gräfe. He first derives the partial-differential equation of the surface under the condition that Brewster's law be fulfilled. It is then shown that the general solution of this equation may be written $F = g(\log r + n\phi)$, where $g$ means any arbitrary function of the argument within the parentheses. It is thus shown that the general polarization surface is generated by the revolution around the proper radius vector of a rigid logarithmic spiral so constituted that the constant angle between any radius vector and the

tangent at its extremity is equal to $\tan^{-1} n$. It is also proved that no other surface can satisfy the requirements of the problem.—*Verh. d. Deutsch. Phys. Gesell.*, **13/16**, 103, 1918.

H. S. U.

9. *Aviation;* by BENJAMIN M. CARMINA. Pp. ix, 172, with 92 figures. New York, 1919 (The Macmillan Co.).—"In the compilation of this book, the guiding principle has been to use matter of actual theorico-practical value to the aviation students to enable them to work knowingly." The successive chapters are devoted respectively to the following topics: theory of flight, aëroplane construction, rigging, propellers, maintenance, and flight hints. The explanations and "theory" are clearly presented and they seem to be as thorough and reliable as is possible under the two restricting conditions consistently fulfilled by the text-proper, namely (a) the hypothesis that the student has had no previous acquaintance with the subject, and (b) the complete absence of even the most elementary mathematics. The line diagrams are numerous and they illustrate the text admirably.

The appendix deals with aërodynamical formulæ and calculations. Nearly all of the typographical and notational errors are confined to this section. The sentence immediately following the second formula on page 135 is especially confusing. A very useful glossary of definitions of technical terms, arranged alphabetically, precedes the index. In conclusion, the writer of this brief notice desires to commend the scientific spirit of the text in general, and to endorse the quotation (p. 157): "The metric system removes the confusion arising out of the excessive diversity of weights and measures prevailing in the world, by substituting in place of the arbitrary and inconsistent systems actually in use, a single one constructed on scientific principles and resting on a natural and invariable standard."

H. S. U.

10. *Molecular Physics, Second Edition;* by JAMES ARNOLD CROWTHER. Pp. viii, 190. Philadelphia, 1919 (P. Blakiston's Son & Co.).—A careful comparison of the latest edition with the first (see **39**, 314, 1915) shows that the revision has been thoroughly done and that the scope of the text has been materially extended. The number of chapters has been increased from nine to ten, the titles of the sixth and seventh now being respectively "The Structure of the Atom" and "The Electron Theory of Valency." All of the typographical errors which we detected in the first edition have been corrected in the second, and a subject index has been added. On the whole, the author's desire "to present a coherent and intelligible account of the present state and most recent advances in the electron theory of matter" seems to be fully realized in the present edition.

H. S. U.

## II. Geology and Natural History.

1. *Western Australia Geological Survey.*—The study of the mineral resources of Western Australia during the year 1917 has resulted in the addition of five bulletins to the already creditable list of publications of the Western Australia Survey. Bulletin 71, "The Gold Belt North of Southern Cross including Westonia," by T. Blatchford, and C. S. Honman, is the third and last report dealing with the Yilgarn Goldfield—a region chiefly of pre-Cambrian rocks which present some unusual features. Bulletin 73, "The Geology of the North Coolgardie Goldfield: The Yerilla District," by C. S. Honman, R. A. Farquharson, and J. T. Jutson, deals with a series of sediments, volcanics, and intrusive rocks which closely resemble the Huronian of the Lake Superior region. Bulletin 74, "Miscellaneous Reports," contains ten short papers on gold, phosphate, graphite, and clay. Bulletin 75, "A Geological Reconnaissance of the Country between Laverton and the South Australian Border including part of the Mount Margaret Goldfield," by H. W. B. Talbot and E. de C. Clarke, presents the salient geological features of a region heretofore unknown. The 500 miles of traverse with a carefully equipped camel train were over a peneplained region of remarkable flatness at an average elevation above sea-level of about 1500 feet. Low mesas and knobs of igneous rock rise above the surface, and the sand ridges which characterize central Australia are here well represented. The geological formations studied are metamorphosed dolerites, granites, and porphyry dikes of pre-Cambrian age, lavas, conglomerates, and limestones of Ordovician (?) age, and the highly interesting Wilkinson Range Series—horizontally bedded sandstones, clay stones, and bowlder beds of glacier origin. This series extends over an undefined but very large area and leads to the conclusion that southward-floating icebergs were depositing detritus in latitude 26° 30′ S. during late Mesozoic or Tertiary age. Bulletin 76, "Interim Report on the Graphite Deposits at Munglinup, Eucla Division," by T. Blatchford, is the first of a series of regional reports on graphite. The Munglinup ore appears to be in part the alteration of pegmatite and in part the product of sheared and weathered basic rock. H. E. G.

2. *The New Zealand Institute Science Congress, Christchurch, 1919.*—The July, 1919, number of the New Zealand Journal of Science and Technology is given up to papers, discussions, and resolutions of the Science Congress held at Christchurch. In many respects this Congress was the most significant scientific event in the history of New Zealand. The war had shown the relatively backward state of scientific investigation in New Zealand, the lack of coordination of research, and absence of financial support for the study of problems bearing

on the development of natural resources. Under the guidance of Dr. L. Cockayne, President of the Congress, stock was taken of the present state of the many problems affecting agriculture, forestry, engineering, and other national activities and methods for improvement suggested and discussed. In the section on biology and agriculture, 23 papers were presented—the titles including plant diseases, seed testing, need of a national herbarium, the status of entomology and fisheries. In the section on geology the need of a better support for a Geological Survey was emphasized. The 12 papers on chemistry, physics, and engineering concern hydroelectric developments and other matters important to the Dominion. The Congress recommended the establishment of a soil survey, a seismologic station, a magnetic survey, a Dominion herbarium, official bench marks, standard time. The government was urged to appoint a paleontologist and to take more vigorous action in preserving the native fauna. H. E. G.

3. *Descriptions and Revisions of the Cretaceous and Tertiary Fish-Remains of New Zealand;* by FREDERICK CHAPMAN. New Zealand Department of Mines, Geological Survey Branch, Palaeontological Bulletin 7, 1918. Pp. 47, 9 pls., 1 map, 2 figs.—Fish remains numbering 551 and including the collections figured by J. W. Davis (Sci. Trans. Roy. Dublin Soc. ser. 2, vol. 4, 1888) have been found at 34 localities in New Zealand. They belong to the following genera:

| | | |
|---|---|---|
| *Notidanus* | *Lamna* | *Callorhynchus* |
| *Synechodus* | *Isurus* | *Thrissopater* |
| *Cestracion* | *Carcharodon* | *Scombroclupea* |
| *Galeocerdo* | *Pristiophorus* | *Diplomystus* |
| *Carcharias* | *Trygon* | *Labrodon* |
| *Scapanorhynchus* | *Myliobatis* | *Sargus* |
| *Odontaspis* | *Ischyodus* | |

Eleven species are assigned by Mr. Chapman to the Cretaceous, 27 are found only in the Tertiary Series, and 5 are common to the Upper Cretaceous and Tertiary. "The existence of a passage series (Cretaceo-Tertiary) with closely annectent elements" supports the evidence from the Foraminifera that no very definite break occurs up to the Miocene. Another contribution is thus made to the much discussed question of the extent and significance of the unconformities? between the Amuri limestone (late Cretaceous) and the Weka Pass stone (Eocene), and between the Weka Pass stone and the younger formations.

H. E. G.

4. *The Prickly Pear in Australia;* by W. B. ALEXANDER. Institute Science and Industry, Melbourne, Australia, Bulletin 12, 1919. Pp. 48, 1 pl., 16 figs.—The prickly pear (*Opuntia inermis*), introduced into Australia as a garden plant, found a congenial home and has become a formidable enemy to agricul-

ture and stock raising. It already covers 22,000,000 acres of land and is spreading at the rate of 1,000,000 acres a year. Attempts to utilize the cactus for fodder, fiber, and other purposes have been unsuccessful, and no inexpensive method for ridding the land of this pest has been found. The committee recommends a search for predatory fungi and insects and the expenditure of $40,000 a year on investigations. H. E. G.

5. *United States Geological Survey;* GEORGE OTIS SMITH, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vol. 48, pp. 75-77):

FOLIOS.—No. 209. Newell Folio, South Dakota; by N. H. DARTON. Pp. 7, with 3 maps and 1 sheet of illustrations.

PROFESSIONAL PAPERS.—No. 112. Upper Cretaceous floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama and Georgia; by E. W. BERRY. Pp. 177; 33 pls., 12 figs.

No. 113. Iron-depositing Bacteria and their geologic relations; by E. C. HARDER. Pp. 89; 12 pls., 14 figs.

No. 120. Shorter contributions to general geology; DAVID WHITE, chief geologist. Pp. 208; 37 pls., 19 figs. Contains 9 papers by 10 authors, previously published separately.

No. 125-A. An Eocene flora from Trans-Pecos, Texas; by E. W. BERRY. Pp. 1-9; 3 pls., 2 figs.

BULLETINS.—No. 666-GG. Our Mineral Supplies, bibliography. Pp. 58.

No. 669. Salt resources of the United States; by W. C. PHALEN. Pp. 282; 17 pls., 16 figs.

No. 678. Clays and shales of Minnesota; by F. F. GROUT; with contributions by E. K. SOPER. Pp. 256; 16 pls., 38 figs.

No. 683. The Anvik-Andreafski Region, Alaska (including the Marshall District); by G. L. HARRINGTON. Pp. 68; 7 pls.

No. 687. The Kantishna Region, Alaska; by S. R. CAPPS. Pp. 114; 17 pls., 6 figs.

No. 688. The Oil Fields of Allen County, Ky., with notes on the oil geology of adjoining counties; by E. W. SHAW and K. F. MATHER. Pp. 125; 10 pls., 10 figs.

No. 690. Contributions to Economic Geology, 1918. Part I. Metals and nonmetals except fuels; F. L. RANSOME, E. F. BURCHARD, and H. S. GALE, geologists in charge. Pp. 149; 5 pls., 11 figs.

Also special parts of Nos. 691, 692, 710, 711.

WATER SUPPLY PAPERS.—No. 425. Contributions to the Hydrology of the United States, 1917; N. C. GROVER, chief hydraulic engineer. Pp. 161; 14 pls., 7 text figs.

No. 429. Ground water in the San Jacinto and Temecula Basins, California; by G. A. WARING. Pp. 113; 14 pls., 15 figs.

No. 446. Geology and Ground waters of the western part of San Diego County, Cal.; by A. J. ELLIS and C. H. LEE. Pp. 321; 47 pls., 18 figs.

No. 457. Surface Water Supply of the United States, 1917.

Part VII. Lower Mississippi River Basin. Pp. 35, xxxii; 2 pls.

No. 485. Surface water supply of Hawaii, July 1, 1917, to June 30, 1918; N. C. Grover, chief hydraulic engineer; C. T. Bailey, acting district engineer. Pp. 169.

Mineral Resources. Numerous advance chapters for 1917, 1918.

6. *Foliation and Metamorphism in Rocks;* T. G. Bonney. Geological Mag., vol. 6, pp. 196-203, and 246-250, 1919.—This paper is a summary statement of the causes of foliation in rocks, and is suggestive of the criteria by which an original foliation is to be distinguished from that in metamorphic rocks. Professor Bonney's long experience began about the time that microscopic methods of rock study were introduced. It is easy for him to support his conclusions with specific examples in many parts of the world.

Foliated rocks are classed as due to (*a*) motion of partly solidified magma, or if associated with banding, in many cases to movement of two partly mixed magmas; (*b*) pressure acting on either igneous rocks or sediments, with later recrystallization in most cases. Each class is illustrated by half a dozen localities and references are given to conclusive descriptions, largely the work of the author himself. Some descriptive passages seem to indicate lit-par-lit injection, but the process is not named.

F. F. G.

7. *Observations on Living Lamellibranchs of New England;* by Edward S. Morse. Proc. Boston Soc. Nat. Hist., 35, No. 5, p. 139-196.—Although the shells of most of the species of marine bivalves of the New England coast were described and figured many years ago, notably in Gould's Invertebrata of Massachusetts, 1841, and in Binney's revision of the same, 1870, the animals themselves have been but little studied. Professor Morse has made observations extending over many years on the living animals of New England lamellibranchs, and in this paper describes and illustrates by excellent outline drawings such parts of the living animals as can be seen protuding from the shells when the animals are in full activity. Forty-eight species are thus illustrated, in many cases with successive growth stages. It is interesting to note that Professor Morse made one of these drawings as early as 1855, since which time he has returned to the study of the biology of the lamellibranchs as occasion permitted until he has become acquainted with all except the more inaccessible species. He justly deplores the apparently needless alterations in the nomenclature of the species which have occurred in the meantime. W. R. C.

8. *Elementary Biology; An introduction to the Science of Life;* by Benjamin C. Gruenberg. Pp. x, 528 with 261 illustrations. Boston and New York, 1919 (Ginn & Co.).—The present tendency of biologists to emphasize the habits, life histories, activities and economic importance of organisms is well illustrated in this excellent introduction to the Science of Life. The

artificial barriers by which some teachers have endeavored to separate the life of animals from that of plants are entirely lacking in this book, which rightly seeks to give the reader a broad appreciation of the unity of vital phenomena, and thus enable him to understand the real meaning of evolution. Not only is the general conception of the book sound, but the treatment of the various topics is clear and concise. The breadth of treatment and inclusiveness of the subject are indicated by the titles of the parts into which the book is divided: I, The World in which we Live; II, Life Processes of the Organism; III, The Continuity of Life; IV, Organisms in their external Relations: V, Heredity and Evolution; VI, Man and other organisms.

The illustrations likewise deserve high praise; they are largely original, well executed, and, what is more important, convey the information desired. In a few cases, as in fig. 250, the diagrams do not conform to the actual conditions, and in the text also generalizations are sometimes carried slightly further than the facts warrant. But these are minor deficiencies in a book of unusual excellence. W. R. C.

## III. Miscellaneous Scientific Intelligence.

1. *National Academy of Sciences.*—The autumn meeting of the National Academy was held in New Haven on November 10 and 11; Dr. Charles D. Walcott, the President, presided. About fifty members were in attendance and the list of papers was long and included a number of particular interest. At the dinner, held on Tuesday evening, the Elliott medal, established in 1916 by a bequest of $10,000 from Margaret Henderson Elliott, was awarded to William Beebe of the American Museum of Natural History for his work, extending over seven years, on the pheasants of the far East. It was also voted to award a medal to Herbert C. Hoover, at the coming April meeting in Washington, for his distinguished service in the "application of science to the public welfare" in food distribution.

## Obituary.

Professor J. W. H. Trail, who has held the Regius chair of botany in the University of Aberdeen for forty-two years, died on September 18 at the age of sixty-eight years.

Dr. Cyril G. Hopkins, head of the department of agronomy in the University of Illinois, died on October 6 at the age of fifty-three years. His death occurred at Gibraltar after a brief illness, when on his way home after a year's study of the exhausted soils of Greece.

Dr. Charles Henry Hitchcock, the geologist, died on November 6 at Honolulu. He was the son of Edward Hitchcock, a notable figure in the early development of geology in this country, and was himself professor in Dartmouth College from 1868 to 1908; he made many contributions to the geology of northern New England.

# INDEX TO VOLUME XLVIII.*



* This Index contains the general heads, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY; under each the titles of Articles referring thereto are included.

X)

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